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A Control Chart Approach to Manufacturing Expense

by **DANIEL J. DUFFY**

Department of Mechanical Engineering, Polytechnic Institute of Brooklyn

THIS article is in the nature of a speculation—hopefully a fruitful one. The question that it attempts to answer is: How can *control limits*[1] be objectively established for the appraisal of manufacturing expense information?

First, the nature of statistical control will be discussed in general. Then the mechanics of the Shewart control chart—upon which it is planned to base the proposed method—will be outlined.

Proceeding from this approach, the elements of factory expense will be examined and a way of arriving at control limits for each class will be presented. The operating significance of such limits will be considered.

While the ideas presented are speculative in the sense that they have not been tested, they are, in so far as is possible, founded on experimental evidence and experience. At least, this is not the speculation of science fiction.

STATISTICAL CONTROL

Take a rubber ball in a room that is reasonably free from vibrations and air currents and drop it from a specified height to the floor. Note the height to which the ball bounces. Repeat this procedure, dropping the ball from the same height each time on to the same spot on the floor. Continue to note the height to which it bounces.

Now, if the measurements that are made of the height of the bounce are compared, it will be found that they are not all the same. Such variability is not surprising. Nor, however, is it unusual to consider the possibility of eliminating variation so that the ball always bounces to the same height. This consideration leads to the heart of the concept of statistical control.

The causes of the variability of bounce height may be considered as coming from two categories:

1. Assignable causes.
2. Chance causes.

Assignable causes are irregular causes (as opposed to those continually affecting the process) that may usually be ferreted out and eliminated with an *economical* expenditure of energy. For example, in the ball-bouncing experiment, if an electric fan were in use during a part of the experiment, it might be the cause of variation that could easily be removed. On the other hand, *chance* causes are those that may be ascribed to a multitude of sources which individually have a small constant effect on the total variability. They are usually from a practical viewpoint unknowable because removing them might require almost infinite knowledge to arrive at methods for detection. A state of *statistical control* is said to exist when the assignable causes of variation have been removed. When the assignable causes are eliminated the constant chance causes still remain and we have statistical control—but *not* the absence of variability. The height to which the ball bounces will never be constant.

What has been done here is to *state*, not argue, the nature of statistical control, and to assert that the concept applies to the ball-bouncing experiment. Actually, it would be impossible to argue statistical control; there must be an appeal to experience. The acceptance of the concept depends upon whether almost unknowable constant causes are conceded. Our experience, it is believed, would suggest that this is true.

Consider some of the many causes of variation that can affect the ball-bouncing experiment. Rotation of the ball will cause it to bounce on a different spot. The height from which it is dropped will vary within the expected error of measurement. Vibration will not be absent from the floor. Air currents, however slight, will be present. If the ball is dropped by hand, tremor will be involved. It is possible to think of many more constant causes of variation that might be impossible to detect and eliminate.

This trivial ball-bouncing experiment involving a common physical event has been introduced to illustrate the meaning of statistical control before applying the concept to the more controversial area of cost. Before proceeding to this, an operational method of separating assignable and chance causes will be described—the Shewhart control chart.

THE SHEWHART CONTROL CHART

To give useful meaning to the concept of *chance* causes and assignable causes there must be an operational

[1] The term control limits will be discussed in some detail later in the presentation. It may be taken at this point to mean the limits within which manufacturing costs may vary without resulting in some action being taken.

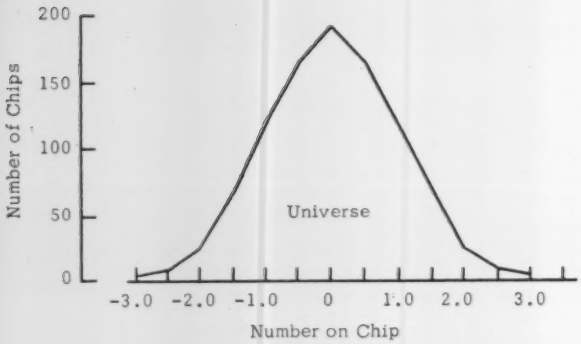

FIG. 1. A Frequency Distribution of the Numbered Chips in the Shewhart Bowl (7, p. 166).

method of detecting them. This method exists in the Shewhart control chart.

A complete explanation of Shewhart's procedure would be incomplete except in a large volume. Only the framework of ideas upon which the control concept rests will be presented. Details which are readily available elsewhere could only distract from the main purpose of this paper (5) (7).

Shewhart assembled a bowl of 998 chips and marked them with numbers ranging from −3.0 to 1.4. Most numbers appeared on more than one chip (7, p. 165f). A frequency distribution of the numbers in the bowl is shown in Figure 1. He reasoned that this bowl (and others he constructed) would be as close to a constant chance cause system as could be obtained in life.[2] If he drew samples from the bowl and the behavior of the samples could be predicted by the use of a particular mathematical model, then that model could be used in determining if other systems which were sampled were constant chance cause systems. The choice of the particular model depends largely upon the nature of the distribution of chips in the bowl. We may limit ourselves to sampling from a bowl marked numerically and one where each chip is marked with one of two colors. The first corresponds to a situation where numerical measurements are made, the second to a situation where items are classified as "defective" and "non-defective," or some other dichotomy.

When Shewhart sampled a numerically marked bowl and averaged the values of some set number of chips—four were tried—the frequency distribution of the sample averages resembled a bell-shaped distribution. It could be very nicely described by the equation for this distribution known in statistics as the "normal distribution." The numbers were changed on the chips so that the frequency distribution, instead of the symmetrical picture in Figure 1, had a more lop-sided appearance. Samples were drawn again and still the same sample averages could be approximated very well by the normal distribution. Figure 2 shows a comparison of the mathematical model with observations.

This now gave Shewhart the answer to his problem. The averages of sample observations would fall within limits that could be predicted based upon a normal distribution if a constant chance cause system was operating. If the system contained assignable causes, the means would tend to fall outside the limits of prediction. These limits could be set so any desired percentage of the averaged samples would fall within them (short of 100%) if the constant chance cause system existed.

The control chart for variables—the principles of which were described in the last two paragraphs—is constructed as follows:

1. Measurements are made of a set of samples of a predetermined number taken closely together in time from a process. The average of the measurements is calculated.
2. Additional sets of samples are taken further apart in time from other sets of samples (then the samples within the sets are separated) until about 25 sets are collected.
3. These 25 sets are used to estimate the parameters of the normal distribution of the sample averages. These parameters are numbers that give specific information about the particular shapes

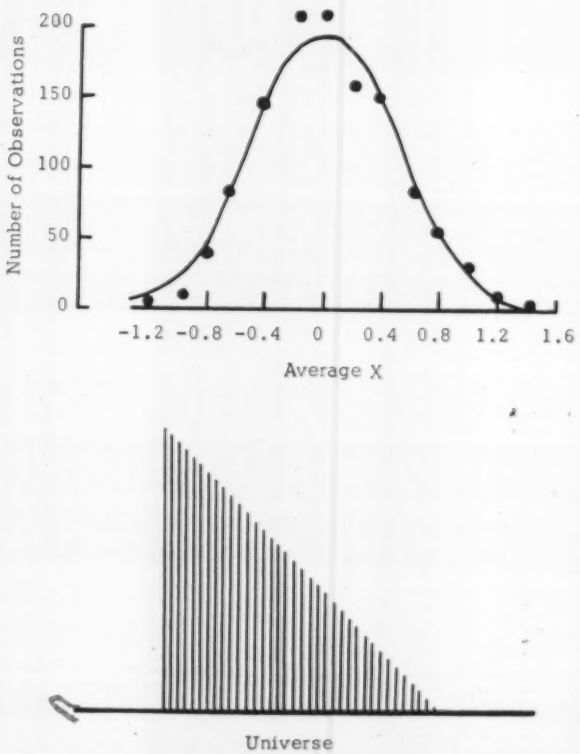

FIG. 2. A Comparison of Observations from a Shewhart Bowl Containing a Right Triangular Universe (Shown as Dots) with a Normal Distribution (Shown as a Continuous Line) (7, p. 182).

[2] The numbers on the chips and number of chips would, of course, remain the same. With adequate mixing of the chips before each drawing, the probability of any one chip being drawn would be about the same as that of any other chip being drawn.

of the normal distribution. While we know the general form of the "bell," it may vary in spread-diameter—(see Figure 3) and location. The diameter or spread is denoted by a parameter called the "standard deviation"; the location is denoted by the "mean."

4. The mean and standard deviations are used to construct the control chart. For an example of a control chart, see (5, p. 90). The average of each set of observations is now plotted against time on the chart.

5. If the points all fall within the control limits, then a state of control—where only a chance cause system is operating—exists, and the limits of the control chart can be used to check future data.

6. If points fall outside the control limits, assignable causes of variation exist in the system and they must be determined and eliminated before limits may be drawn for use with future data.

We have described the situation where variables are measured. A different model is used when the chips are classified into categories such as red and black. This is the binomial distribution. When the division in the bowl between the two categories is about equal and our sample size is above ten, then this distribution strongly resembles the normal. As the percent of one category decreases the distribution becomes increasingly unsymmetrical or lopsided.

The procedure of constructing a control chart when the binomial is used is similar to that for the normal distribution. The principal difference is that the sample in a set of observations must be larger and the percentage of a chosen category in a given sample is computed and plotted rather than the average.

To this brief description—which will be supplemented in certain respects in connection with the application of control charts to cost data—must be added the fact that the control chart is fallible. It will, at times, indicate an assignable cause when none exists and the absence when not only chance causes are at work. However, the control chart procedure makes it possible to control the risk of these errors occurring, and to establish these at some balance. At this balance, the cost of looking for assignable causes that do not exist plus the cost of failing to look for assignable causes when they are in the process are at a minimum. A balance must be chosen because the situation is antithetical: as we decrease one risk the other always increases.

CONSTANT CHANCE CAUSES AND MANUFACTURING EXPENSE

Before proceeding with the application of the control chart to manufacturing expense, the question might be raised if it appears likely that the behavior that produces these expenses is characterized by constant chance causes. First of all, it is evident that there are a multitude of causes affecting the components of factory expense. The labor portion, for example, is influenced by sociological and psychological factors that are numerous and are presently only comprehended in a vague way. Raw materials, as shown by numerous quality control studies exhibit variability in their characteristics that

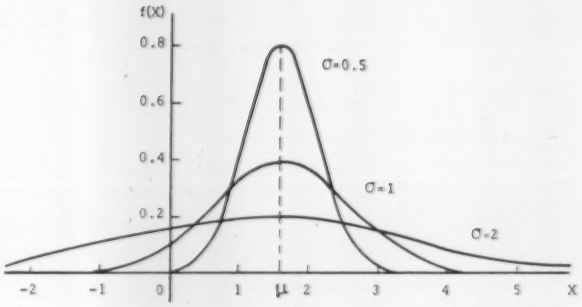

FIG. 3. Three Normal Distributions All with the Same Mean but with Three Different Spreads (6, p. 109).

may be with even greater assurance considered as arising from constant chance causes. Ratio-delay studies indicate that the operation of machines and their breakdown exhibit the existence of constant chance causes at work.

It cannot be proven that constant chance causes exist that influence factory expense any more than it could be proven in the ball-bouncing experiment. This axiom is necessary in order to proceed with the application of the control chart. However, such an axiom should be imtuitively acceptable. To the author, at least, this is so.

DIFFICULTIES OF USING ACCOUNTING FIGURES AS THEY PRESENTLY EXIST

The accounting apparatus presently produces total actual factory unit costs and actual total costs by burden centers. Cannot control charts be constructed from this information that will allow us to separate assignable and chance causes? Unfortunately, the answer for two principal reasons is "no."

Total accounting costs contain allocated factory burden which is apportioned on some arbitrary scheme. The arbitrary nature of this allocation makes it impossible to ascribe meaning to the variability of the total cost. An example is an order. Suppose that the numbers on the chips in Shewhart's bowl represented the direct manhours required to produce one unit of product. Also assume that the accounting system follows the common procedure of allocating burdens on the basis of direct manhours. Simplify the process and say that there is zero cost for materials. The total unit cost of the product will then approximately equal the mean value of the chips in the bowl times the appropriate hourly rate plus mean manhours times the burden rate. Let the burden rate be an actual rather than a standard rate.

If the direct labor remains influenced only by constant chance causes, but the burden is changed because of some assignable causes occasioned by another product, then the control chart for the product or burden center under consideration will falsely attribute an assignable cause of variation to this product or burden center. Assignable causes will appear to be present for every product and department where the burden rate is used, including the

product and department responsible for the assignable causes.

This situation does not change when other burden allocation methods are used. It would also exist when direct labor was not in a state of control but burden charges were under control.

The second reason accounting costs are not suitable for control charting is that the control chart requires data that are the average of several observations. Accounting information usually represents simple observations such as the unit cost for a week or a month. Obviously this limitation is not so serious as the first since data from consecutive periods might be averaged. Nonetheless, there are disadvantages in this approach which will be examined later.

A MEASUREMENT APPROACH FOR CONTROL CHARTS FOR COSTS

It seems evident that the limitations of accounting data preclude their being used for control chart analysis without modification. A method will be presented that utilizes accounting data plus certain supplementary measurements to produce three basic figures for control that are analyzed on three or more separate charts—at least one for direct labor, another for direct materials and a third for burden. A detailed presentation will be made of this method.

DIRECT LABOR: SOME PROBLEMS DISCUSSED

Since the direct labor is customarily reported on some regular basis and identified as to the burden center and product upon which the labor was expended, the rudimentary measurements for a direct labor control chart exist in most accounting systems. Yet some questions must still be resolved.

Should net or gross production be reported? That is, should labor costs for the time of actual production be used and the costs of delays (such as those that occur during machine breakdowns) be subtracted, or should gross labor costs—including delays—be used? First, the gross figure is more readily available. There is no need for extra computations. The need to rely upon the reporting of downtime—sometimes highly suspect information—is eliminated. Also, even the best delay reporting system cannot catch momentary delays. Most important, delays add to the labor cost of the product and therefore, if the net direct labor were computed, it would be necessary to keep a separated account of delays in addition. It does not seem desirable to start a system with detail that might not be demanded.[3]

What should the period of observation be—an hour, day, week or month? It seems safe to say that the period should not be shorter than one day if gross direct labor is charted. There is considerable evidence that within the working day the gross direct labor per unit varies because of what the time study people choose to call "fatigue" (4). Since a trend exists within the day, the charting of gross direct labor would not be in control within the day.

If the gross direct labor per unit for the entire day is used, this trend which is known to exist will not appear and be confounded with other assignable causes that might exist.

While the period should not be shorter than one day, neither does it appear that it should be much longer. As we have seen, taking a one-day period eliminates the "fatigue" trend as a longer period may eliminate other trends or postpone the discovery of an assignable cause: this masking may be highly undesirable. In addition, the observations of several periods must be averaged before being plotted on the control chart in order to determine if an assignable cause has occurred. Long periods will delay this analysis and will also make detecting the specific nature of such a cause difficult because the time of occurrence cannot be sharply pinpointed.

Finally, shorter periods fulfill another important requirement of the control chart. The chart depends upon comparing the variation between a group of observations closely spaced so as to be taken under conditions as much alike as possible, with subsequent groups taken a sufficiently long period away as to disclose substantially altered conditions. That is, if the difference between a group of observations taken under similar circumstances leads us to expect only a certain difference between groups of observations if conditions remain the same, then we may assume substantial changes in conditions and the existence of an assignable cause if this difference is significantly different from what we expected. In order to have a period of substance between groups of observations and yet have data for analysis promptly, it is clearly necessary to make each observation period short.

Observations on products having long cycles to completion might make it necessary to extend the observation period beyond one day. This would be especially important because of the need to estimate the degree of completion of in-process units. A short observation period of long cycle products could mean that a high percentage of the unit direct labor was the result of an estimate of the percent of completion. Since such estimates are usually only rough guesses, the resulting measurements could not be highly reliable.

As Abruzzi has found, different product designs may not be significantly different as far as direct labor required is concerned, and they may be grouped and treated as one product (1). If this is not the case the control chart is not applicable in departments that run many products each only for a short period.[4]

[3] Delays might, of course, be charted, but only if this charting was warranted by the cost of the reporting, charting and investigation that would ensue.

[4] There are situations where a fixed work force is utilized in a department. Obviously the control chart has little use here since when the department is loaded below capacity, gross direct labor per unit (if it may be called that) will necessarily rise.

A PROCEDURE FOR DIRECT LABOR ANALYSIS

In view of the foregoing discussion it would appear that direct labor control charts are applicable in departments that manufacture either a small number of products over a long period of time or several products that have an equivalent direct labor content for long periods. The observation period should be about one day but not less. The mean value of from three to four observation periods that follow consecutively should be taken and plotted on the chart.[5] A group of observations should be taken about once every two weeks with the days observed varying so the same days of the week are not chosen each time. The two-week period is chosen because it would allow a fairly long period between groups of observations so assignable causes can show up and yet produce control information with reasonable frequency. The observation should consist of the total expenditure for gross direct labor during the period divided by the number of units produced by this labor. The equivalent number of unfinished units should be estimated and included in the number produced. This information may be obtained from the daily time tickets plus the foreman's estimate of the degree of completion of work in process. The last item might be ignored if it is not substantial.

If only two control points per four-week period were considered inadequate, more points might be obtained by including a smaller number of observation periods in a group and/or spacing groups of observations closer together. This would change the balance of the risks between looking for assignable causes when they do not exist and failing to look for assignable causes when they are present. The precise number of observations and the spacing between groups can perhaps be best worked out by experience, as it is in statistical quality control work.

The means should be plotted when about 25 groups have been averaged. Then control limits should be computed and drawn with the plotted points. Subsequent points may then be added to the chart.

INTERPRETING DIRECT LABOR CONTROL CHARTS

Either the control chart for direct labor will show all points within the control limits, or assignable causes will be indicated to exist by points falling outside the limits. The first condition will indicate that there are no areas for investigation that will change the direct labor cost without the probable need for extensive and, in all likelihood, expensive investigation and remedial action. The second condition suggests the contrary, that reasonable expenditure of investigation effort and remedial effort can be expected to produce desirable changes.

Of course, investigation may show that assignable causes exist that cannot be corrected. If the workload of a department increases so that a significantly large number of new workers must be employed and trained, the lower productivity of the trainees may pull up the unit cost of a department so that a point will appear out of control on the chart. More probably, the assignable cause will show up as a problem that can be dealt with effectively. For example, a change in plant layout may have been made with the result that operators are delayed waiting for the delivery of parts on which to work.

It would perhaps be proper to discuss the action necessary if a change is desired because of excessive costs, for example, and if the chart shows no assignable causes.

First of all, an extensive program of experimentation would be necessary to determine the causes of the constant-chance-cause variability. The cost of such experimentation may be high because of the need to interfere, at least to some extent, with the normal production process. Even where the experimentation is economical, there is no assurance that the variability of the costs will be so influenced by some variable sufficiently dominant that even extensive experimentation would reveal it. Any variable that can be detected must then be of such magnitude that changing it will make a significant change in the system. In addition, it must be possible and economical to alter the variable.

As an example of a variable that may substantially influence direct labor costs but where little meaningful action can be taken, we have the general state of the economy. In the Hawthorne study, productivity continually rose until the depression (4, p. 140). This dominating variable, which no one company can significantly change, counteracted the favorable effects of the experiment.

One last comment should be made on interpreting the direct labor control chart. If an assignable cause is indicated by a lower cost than a constant-chance-cause system would predict, then a valuable clue to cost reduction is at hand. This out-of-control point may indicate an improved method that was come upon accidently.

A PROCEDURE FOR DIRECT MATERIAL ANALYSIS

Since it is not uncommon for careful records to be kept of the usage of direct materials, the problem is largely one of adapting direct material reports so they cover the same period as that chosen for observation. The degree of the adaptation depends, of course, upon the observation period and present recording method. The last may be suitable as it stands, or it may be necessary to set up a parallel system of recording. Plant situations vary so widely that it is difficult to make useful generalizations.

For control chart purposes, direct material so closely parallels direct labor that it would be repetitious to cover the same ground. Most of the comments about the nature of the data, the observation period to constitute the sample and the interpretation of the chart apply to direct material. When they do not, the exception is obvious.

[5] For a discussion of the economics of various sample sizes and some interesting generalizations about them, see (2).

Yet an exception must be entered to this similarity in two points. First, it would seem of minor value to extend material usage in physical units by the *actual* price per unit. The clerical work would be considerable and the effect of price change would be confounded with change in material usage. Since in many cases price variance for materials is adequately pointed out and readily detected by the cost accounting system, it would be of greater value to focus attention on the physical use of materials through use of a constant unit price. That is, prices usually do not vary according to chance, and any price change will show up as an assignable cause. Since the existence of this price change is well known, the chart has given us no information of value. Besides, the price change may occur when an assignable cause of material usage occurs, and results in this cause remaining undetected because of the masking effect.

The standard constant unit cost would be useful as long as the variance between actual and standard is not too great. Converting the physical units into dollars has the advantage of common units and the possibility of adding material and other costs.

Secondly, it is conceivable that material usage in a well run plant exhibits such small variability that it may be treated as a constant. This may be feasible where the cost of the material is low and it does not offer a profitable target for tight control.

A PROCEDURE FOR OVERHEAD COST ANALYSIS

A Modern Technique for Allocation—To this point we have dealt with the simpler cost elements of factory expense—direct labor and direct materials. They are already being measured and reported on a regular basis. What is required is a procedural change to make this measurement and reporting fit a format that will allow the construction of a control chart. This is not true with overhead costs.

These are the notorious loose ends of accounting. They refuse to fit the useful compartments of burden centers or product classification. The accountant employs allocation methods which are far from satisfying. The crude allotment of overhead costs to departments and products by dollars of direct labor or more complex methods does not result in cost figures that are more than fictions.

One point does, however, become clear in the allocation methods employed by the accountants: *There is the implied belief that perhaps much overhead expense bears a unique relationship to the production of a particular product in a particular department.* The accountant is stopped in the natural consequence of this belief—that of assigning more costs directly to departments and products—by the lack of a feasible and economical method of assigning costs. It does appear that a tool has been developed during the last thirty years to meet this need. This tool is sampling.

In applying sampling to overhead costs two types will be used: a selected sample and a random sample. Each will now be discussed.

Pareto's Rule Applied to Overhead Accounts—In a selected sample we know the characteristics that we want the sample to exhibit and we pick it to exhibit these characteristics. In dealing with overhead we want to concern ourselves only with the accounts that add considerably to the total of overhead expense. Therefore, if we consider studying overhead accounts, we will select as a sample from the universe—or total accounts—only those accounts that contain much overhead expense.

There is power in this approach because of the frequency with which Pareto's rule applies to specific situations. Essentially, Pareto's rule states that if an outcome is the result of a great many sources, investigation will reveal that a small percentage of the sources will be responsible for a large percent of the outcome.[6] Investigations in many fields have revealed situations where the rule applies. Many companies report that a small number of items account for a large percentage of their total inventory evaluations. The Federal Aeronautics Commission reports that a small percentage of airline passengers account for a large proportion of the total passenger miles flown. A small number of causes are often shown to result in a sizeable number of units of a product being rejected. Many other examples may be cited. Frequently about 20% of the sources contribute about 80% of the outcome.

It should be recognized that Pareto's rule cannot be enunciated as the rigid law that it was once thought to be. Its value lies in suggesting that we look for a small number of overhead accounts to contribute a vast amount of the total burden. If this situation exists in fact,[7] then we can control only the most important accounts and yet have control over most of the total overhead expenses. We can minimize the cost of control.

Pareto's rule can also direct attention to the nature of charges to a specific account. Certain accounts may show that a small percentage of the classification of charges account for a large percent of the total expense charged to the account.

In summary, it has been pointed out that a selected sample of the overhead accounts in specific companies may be selected so that an overwhelming portion of the total overhead expenses fall in these accounts. In addition, further investigation of specific accounts may show that only a small percent of the total classification of charges to an account are responsible for a large part of the total charges to the account. Both possibilities point to the opportunity of investigating and controlling overhead at a relatively small number of points and yet

[6] For a graphical example of Pareto's rule see (3).

[7] Several accountants have indicated in conversation that they believe Pareto's rule applies to their companies' accounts. However, no detailed investigation was possible at this point.

maintaining close control over the total overhead of a plant.

Random Sampling—A selected sample will narrow the number of overhead accounts that have to be observed. Random sampling will allow many of these accounts to be observed economically. Essentially, the method suggested here is an extensive application of work sampling to overhead accounts.

Work sampling is a work measurement technique analogous to sampling from the Shewhart bowl when the chips are either black or white. It will be recalled that the model of random sampling from this bowl is the binomial distribution. When only random causes are at work, the distribution of the percentage of chips of a particular color in a sample is predicted by the binomial distribution.

In practice, work sampling consists of taking "instantaneous"[8] observations of an activity at irregular intervals and then computing the percent of observations that fall into various designated categories. A control chart is constructed upon which the percentages in a category are plotted in time-order. Points plotted outside the control limits indicate assignable causes of variation. When a sufficient number of consecutive points fall within the control limits, then all such observations may be pooled and an estimate made of the average percent of the activity that will fall within specified limits. When more than two classifications are used, several control charts must be kept.

In applying work sampling to overhead, the procedure would be to make irregular observations of the activity of an account and classify them as to department and product. These observations would be plotted on control charts. These charts may also be interpreted in dollars if the percent of time an activity devoted to a classification (such as a product) directly relates to cost of the activity.

It is recognized that a certain percentage of overhead cannot be related to any department or product. For example, a talk by the plant manager on the subject of safety to a Rotary Club could not be classified. It is believed that unclassifiable events would in general not represent too large a portion of total overhead. This belief would, of course, have to be confirmed by investigation in particular plants.

However, regardless of the portion of total overhead represented by charges that cannot be classified by product or department, it is still possible to classify and control these expenditures. They can be made a separate category and be represented on a control chart as "nonclassifiable overhead expenses."

The term "work measurement" should not suggest that the sampling procedure is limited to observing and controlling only human work. The technique is more general and it appears likely that it may be employed in connection with many overhead accounts. Certain expense materials, for example, such as machine lubricants, may be traced through sampling to the area of application and the product benefiting from the application.

Some Limitations of Random Sampling—Two objections might be made to using sampling to control overhead:

1. The variation in the portion of plant capacity used will cause overhead to vary constantly, therefore precluding the use of the control chart, to potentially stable situations.
2. Accounts like depreciation, tax, rent and others are constant.

The first objection may be of less importance than it at first appears. More and more plants appear to be running at the practical limit of their capacity. Indeed, with the increasing use of automatic machinery, the penalty for a significant drop in the proportion of plant capacity used is serious enough to force a plant into liquidation. However, even full capacity is not required, only stable capacity use. If the use of capacity at some point tends to be stable, then a control may be used.

Such a chart would be useful for indicating when a change in capacity use-factor was significantly great to warrant greater overhead. That is, change in the use of the capacity of a plant would show up as an assignable cause. If the capacity-use change were not controllable and the new level of use appeared likely to be continued for a long time, then a new chart would be constructed.

Another approach is conceptually possible and widely advocated. That is to construct a trend line through a scatter of overhead expenses plotted against the percent of plant capacity used. Unfortunately, unless enough data are available at many levels of capacity so the control chart may check the stability (or lack of assignable causes) at each level, this approach depends upon luck rather than logic for its success. The "control limits" that may be drawn around the trend line are based on an assumption of a normal distribution of the data at each level of use and the absence of assignable causes when the data upon which the trend line is based were obtained. These are two assumptions that are made only with great risk.

In a summary, it may be impossible in certain cases to apply the control chart because of the unstable capacity factor. This is unlikely to be the situation for all plants and perhaps not even for very many.

Constant Overhead Costs—Depreciation, rent and taxes are examples of overhead costs that are arbitrarily fixed at some constant level throughout a given period. They do not fit into a control chart scheme and they cannot be handled except by methods currently practiced by accountants if we insist upon product or department classification.

[8] "Instantaneous" observation is usually taken to mean the observation first perceived by the observer.

VALUE OF CONTROL CHARTS OF THE ELEMENTS OF FACTORY EXPENSE

A procedure has been outlined for constructing control charts of many of the elements of factory expense. The value of these charts lies in the following:

1. The control chart gives an operational method of directing attention in cost control to those causes—called "assignable"—of cost variation that may be most easily found and eliminated (if this is desirable) and that bring about the largest changes.

2. The elementary control charts of unit costs by cost centers may be combined into department and plantwide charts and into charts of semitotal* unit costs. These allow the profitability of products to be controlled and the effectiveness of department management to be judged. Under such a system, a department manager does not oscillate between success and failure because of the random causes that affect the costs in his department.

3. Estimates of certain elements of cost may be made with predetermined precision. These estimates may be relied upon to be proven close to the costs to be experienced if a stable state exists.

CONCLUSION

The statistical control chart concept has proved to be of great power in quality control. Can it make an equal contribution to cost control? The answer must lie not only in rational argument, but in experimentation. As this article has indicated, control chart application to costs depends upon several important assumptions holding true in practice. If these are not in opposition to experience, at least in some cases, then there is a practical use for this concept.

Yet we must go beyond experimentation itself. New approaches must be conceived before being tested. Thought must be given, for example, as to how depreciation costs can pass from the realm of the arbitrary to the meaningful and the true depreciation portion of a unit cost known and controlled.

* Because not all overhead can be accurately traced to department or product, charts cannot be kept of true total costs.

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A Method for Designing Irreversible Overhead Loop Conveyors

by **T. T. KWO***

Home Laundry Department, General Electric Company

THE OBJECT discussed in this article is the simple, irreversible, overhead loop conveyor found in many modern manufacturing plants. This generally consists of a chain moving in a fixed loop with equally-spaced carriers, or sometimes, equally-spaced hooks, hanging from the chain for transporting parts or material supplies from one process area to the next. Human materials handlers are used in loading and unloading the parts while the conveyor is continuously moving at a constant speed. No switching device is provided to divert the carriers to a different path. Figure 1 shows a schematic diagram of such a conveyor in its simplest form. This type of conveyor is widely used today because of its simplicity, and hence low cost. With the trend toward automatized manufacturing operation in all industries, it seems reasonable that still more conveyor systems of this type will be used. However, past experience with these conveyors seems to indicate that unless generous floor storage is provided at both loading and unloading points, the following undesirable situations often arise:

1. At the loading point no vacant carriers will be coming by for some time just when vacant carriers are needed.
2. At the unloading point, no parts will be coming by for some time just when parts are needed.
3. Both of the above situations at the same time.

Any of these can cause interruptions of normal production, revisions of preplanned schedules, and all the ensuing confusion and frustration. An unhappy situation thus seems to have arisen. On the one hand, it seems desirable to have more conveyors of this kind; on the other hand, it seems desirable to have less.

This writer and a group of his colleagues at the Home Laundry Department of the General Electric Company made a comprehensive study of these problems in the sprin_ of 1956. Some of the findings have been presented in an earlier paper (3), and a number of unpublished company reports (2). It was discovered that, contrary to common understanding, a conveyor of this kind need not be a source of trouble. It can be made to function satisfactorily and independently. The main point is that a conveyor is really one of many kinds of mechanisms or systems linking two process areas together. As a linkage mechanism it is required to effect a smooth transformation of the output flow of one process area into the input flow of the next. A smooth transformation implies that two functions must be performed properly. Spacially, the transformed flow must occur at the right place; this is the *delivery* function. Temporally, the transformed flow must be of the right pattern, or at the right rate in simple cases; this is the *storage* function.

Two types of conveyor problems were also differentiated: The *operation* problem and the *design* problem. In a conveyor operation problem, an existing conveyor system is given. The only thing that is controllable is generally the speed of the conveyor, though sometimes it may be possible to alter the loading-unloading schedule of the conveyor so that a satisfactory conveyor speed can be found. To solve the operation problem computer simulation methods have been devised to find conveyor speeds that are "workable" and, if desired, also optimal by some chosen criterion. In a conveyor design problem, one that has not previously been treated, the number of alternative solutions appears to be confusingly high, since here even the conveyor parameters such as conveyor length and carrier capacity are subject to determination. It is the purpose of this article to crystallize the design problem and to present a method of arriving at feasible conveyor designs.

STATEMENT OF THE PROBLEM AND THE ASSUMPTIONS

A typical conveyor design situation is the following: A manufactured part of known weight, volume and other physical characteristics goes through two processing areas in succession. Area A has an average output rate of r_L and area B has an average input rate of r_U. A conveyor of the type described is to be used to link together the two areas which are at a distance of D apart. (See Figure 1.) What should the specifications of the conveyor be?

Such a design problem is generally solved in three stages. First, parameters of the conveyor related to its performance are specified. Then these parameters are translated into mechanical and electrical terms such as the number, size, and placement of motors, and the structure of the tracks. Finally, these electromechanical spec-

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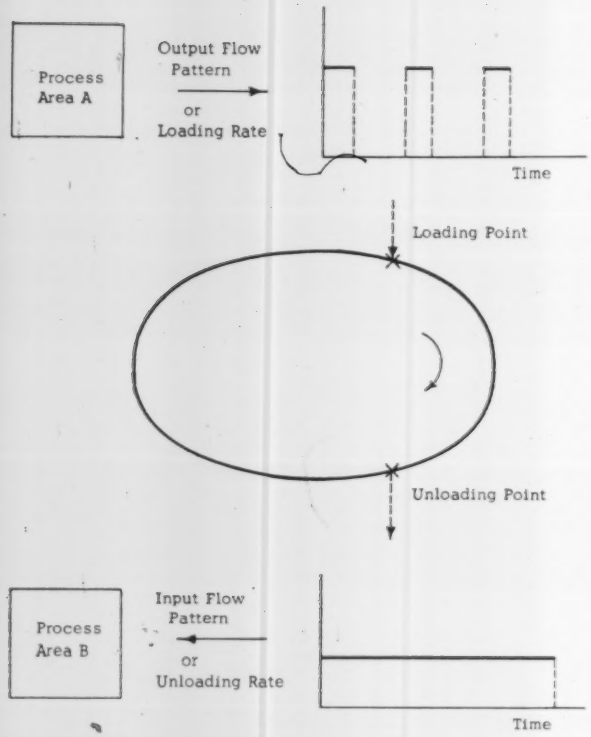

FIG. 1. Schematic Diagram of Simple Conveyor.

ifications are in turn rendered into monetary terms for examination and evaluation by the designer and management. To this writer's knowledge, not much is available in current literature to help the designer in the first stage (5) (6). Current conveyor design practice seems to start from the second stage, using some ventured estimates of the needed conveyor parameters. The design problem posed here is the first stage problem, the specification of feasible conveyor parameters and the operating conditions under which the conveyor is to carry out its storage-and-delivery function. Though the method of solution presented is capable of producing many equally workable designs, no discussion of the criterion for selecting the best design will be given other than the mere recognition of the importance of economic considerations. The designer himself must supply the selection criterion appropriate to his specific design situation.

Arising necessarily with the storage-and-delivery function is the question of between-area inventory, or buffer stock, and its accommodation. This is a complex problem that has received much treatment in current literature (1) (4) (7). Magee in an illuminating discussion (4) classifies inventories, by their functions, into a. process and movement inventories—to take into consideration the time required to process and move the parts, and b. organizational inventories—to gain organizational flexibility in the process areas. The latter inventories are further classified into lot-size inventories, fluctuation stocks, and anticipation stocks. Such concepts are equally valid when the process areas are linked together by a conveyor. Fluctuation stocks, particularly, must be present to absorb random manufacturing disturbances. However, these concepts must be treated in a new light. Specification of these inventories in terms of stock levels alone is not useful to the conveyor designer. That is a static concept. In contrast, the vehicle accommodating the inventories is dynamic. Moreover, the conveyor is moving in a fixed *loop*. There must be buffer accommodations as well as buffer stocks, and both must not only be made available, but also accessible. Hence specification of inventories, to be meaningful, must be in terms of their effect on, or demand for, the conveyor capacity in a dynamic sense. (See (3) for a fuller discussion.)

Traditionally, this dynamic capacity requirements concept has not been recognized. The conveyor designer is able to avoid facing the real issue by providing ample *stationary* buffer stocks at both the loading and unloading points. It must be recognized that these are buffer stocks between the conveyor and the process areas, not between the two process areas. In Magee's term, they "decouple" the conveyor from the process areas, thus easing the demands on the conveyor. It is the contention of this writer that since the operations of a conveyor are now better understood, stationary buffer stocks need no longer be used. It is true that it may still be desirable to have a certain amount of stationary stock to gain greater flexibility in the process areas, and that some stocks such as anticipation stocks need not ordinarily be on the conveyor. It is equally true that there are many situations for which conveyor storage of all stocks is the most economical way, provided the functioning of such a conveyor is fully understood (for example, the case of light but bulky fabricated parts). The design procedure presented in this article assumes that the conveyor is to accommodate all the between-area stocks.

Thus, the development of a method to solve the conveyor design problem as defined boils down to this: Find a method of expressing various between-area stocks in terms of dynamic conveyor capacity requirements. Find the conditions, expressed in terms of conveyor parameters, under which the conveyor will meet these capacity requirements in performing its storage-and-delivery function. The answers to these are found in the principles of conveyor operations described in the following section. Strictly speaking, conveyor capacity requirements of various between-area stocks and workable operating conditions for the conveyor, being governed by loading and unloading which in reality may be quite irregular, can only be jointly determined by simulation methods (3). In a design situation it is reasonable to sacrifice some realism and work with a loading-unloading schedule of a simple ideal form. Such a schedule may be regarded as representative of "normal" operating conditions. If this is

done, then it is possible to derive the workable operating conditions independently. It also becomes logical to regard various between-area stocks either as *operating* stocks or *reserve* stocks, thereby simplifying the job of finding their capacity requirements. The loading-unloading schedule to be assumed is simply an elementary cycle repeated many times (Figure 1). Information on this elementary cycle, consisting of the output rate of the feeding area and the input rate of the fed area, and their respective durations, determined presumably by economic lot size considerations, is thus considered as one of the basic given design data.

When loading and unloading follow the assumed pattern, accumulation and depletion of parts take place on the conveyor in every elementary cycle thereby giving rise to the operating capacity requirements. The differences in rates and locations of loading and unloading cause the accumulation and depletion of parts. These are requirements due to, in Magee's terms, lot-size inventories and process and movement inventories. Mathematical expressions for these capacity requirements in even such a simple case have not yet been developed. Consequently it will be assumed that the numerical method described in a later section is adopted as part of the design procedure.

When loading or unloading deviates from the assumed pattern, reserve stocks and reserve accommodations become necessary. Reserve stocks, or in Magee's terms, fluctuation stocks and anticipation stocks, are needed to absorb increases in unloading and decreases in loading. Reserve accommodations are needed to absorb decreases in unloading and increases in loading. Since by assumption no stationary storage is permitted, these considerations require that part of the conveyor capacity be reserve capacity meeting these requirements. A thorough discussion of the determination of the sizes of these reserves is beyond the scope of this presentation. Some rigorous methods of treatment may be found in the references already cited. Crude rules of thumb are often used in design situations, because even when rigorous methods happen to be available, lack of the necessary data still can make them inapplicable. It will be assumed here that the sizes of these reserves are already determined by some method and their sum is given as the total reserve capacity to be provided. This is another of the basic given design data.

PRINCIPLES OF CONVEYOR OPERATION

To understand fully the method of conveyor design presented in this article, it is necessary to understand how a conveyor of the type described functions. To do this it is helpful to visualize such a conveyor reduced to its essentials. The situation is schematically illustrated in Figure 1. For such a conveyor to function satisfactorily between two process areas with output and input flows as indicated, the following three basic principles must be observed. These are all fairly simple and are all related to the speed of the conveyor in some way.

THE UNIFORMITY PRINCIPLE

This is a rather important requirement. It has been found that to avoid the difficulty of not having vacant carriers at the loading point when they are needed, and that of not having parts at the unloading point when they are needed, the fundamental rule is simply to try to load and unload the conveyor evenly or uniformly over the entire conveyor loop to begin with. Since the revolution time of the conveyor determines the number of times a section of the conveyor passes the loading point (or unloading point), it is closely related to the uniformity of distribution of parts over the conveyor. For a given loading-unloading schedule, some values of the revolution time may result in uniformity, or a condition closer to uniformity, than other values can. When the schedule is rather chaotic, these "admissible" or "workable" values of the revolution time can only be determined experimentally, or through the use of simulation methods on electronic computers. When the schedule exhibits regularity, consisting of a series of elementary loading and unloading cycles such as is shown in Figure 3, values of the workable revolution time may be readily determined without tedious computation by examining the *elementary cycle*. The conditions that must be met simultaneously are given by

$$(N_T T)/W = N_W, \text{ a positive integer not equal to one, with } N_W \neq N_T, \qquad \text{Eq. 1}$$

$$(N_T T_L)/W = \text{a positive integer, } \textit{or}$$
$$(N_T T_U)/W = \text{a positive integer,}$$
$$\text{with } T_L + T_U = T, \qquad \text{Eq. 2.}$$

where

N_T = number of elementary cycles considered.
T = cycle time (duration of elementary cycle).
W = revolution time of conveyor.
N_W = 2, 3, · · · , integer.
T_L = loading duration in the elementary cycle, or more appropriately, time when conveyor has a net gain of parts.
T_U = unloading duration in the elementary cycle, or more appropriately, time when conveyor has a net loss of parts.

Eq. 1. simply says that after a certain interval of time, $N_T T$, all things are to return to what they were at the start. This time interval can be one elementary cycle or N_T elementary cycles. This is quite reasonable in practice, because neither accumulation by loading nor depletion by unloading can go on forever. After some time lapse, the two have got to be equal to each other. N_T cannot be equal to N_W, because if they were, any section of the conveyor would get the same loading-unloading effect

from cycle to cycle and uniformity would never be achieved. The same reasoning rules out $N_W = 1$.

Eq. 2. spells out the uniformity requirement. It states that the total accumulation (or total depletion) in the time interval $N_T T$ must be such that it can be shared evenly by the entire conveyor. In terms of time this means that the time lapse over which there is a net gain (or net loss) of parts must be an integral multiple of the revolution time. Since total accumulation equals total depletion in the time interval $N_T T$, either one of the two expressions in Eq. 2. will suffice.

THE CAPACITY CONSTRAINT

This simply dictates that the accommodations furnished by the conveyor should be at least equal to the accommodations required. Symbolically, this constraint is expressed as

$$mqv/L = mq/W = qv/s \geq K \qquad \text{Eq. 3.}$$

where

m = total number of carriers on the conveyor.
q = capacity of a carrier (number of racks per carrier), or, number of parts a carrier can accommodate.
v = speed of conveyor.
L = length of conveyor.
$W = L/v$ = revolution time of conveyor.
$s = L/m$ = spacing between carriers.
K = accommodations required per unit time; a constant determined by the revolution time of conveyor, the operating capacity, and the total reserve capacity to be provided.

The left hand side of this inequality is the number of racks passing by any point in a unit time when the speed of the conveyor is v (or equivalently, when the revolution time is W). This is the potential capacity of the conveyor.

The right hand side is the number of accommodations required in a unit time. This depends on the amount of expected "operating" capacity requirements, the amount of "reserve" capacity to be provided on the conveyor, and the revolution time of the conveyor. More will be said about the determination of K in the next section.

Observe that both capacity and requirements have been put on a per unit time basis by relating them to the revolution time of the conveyor. Since revolution time is more convenient to use in design problems than its equivalent, conveyor speed, it will be referred to more frequently henceforth in this article.

THE SPEED RULE

This defines a range of permissible speeds for the conveyor. At the low end this is set by the loading rate or the unloading rate, whichever is higher. At the high end this is determined by the technological (electromechanical) restrictions on the conveyor, or on the human materials handlers' agility in handling the parts when loading and unloading, whichever is lower. Symbolically, this is expressed as

$$\text{Max}\,(r_L, r_U) \leq v/s \leq \text{Min}\,(1/t_L, 1/t_U, v_c/s) \qquad \text{Eq. 4.}$$

where

r_L = loading rate.
r_U = unloading rate.
v = speed of conveyor.
s = spacing between carriers.
t_L = average time to load a part on the conveyor.
t_U = average time to unload a part off the conveyor.
v_c = maximum speed of conveyor that is technologically allowable.

Generally speaking, neither the lower speed limit nor the upper speed limit is a real restriction. At the low end, the allowable speed can be quite low because a close spacing between carriers can generally be used. Also, in reality an ample reserve stock of parts and reserve carrier capacity are generally provided on the conveyor, thereby removing much of the need for the conveyor speed to be within the indicated limits. At the high end, the limits resulting from both the technological considerations and the materials handlers' capabilities are high. Moreover, in reality the materials handlers are usually allowed enough room to reach a span of carriers, i.e. they are not confined to a mathematical point but are allowed to walk with the moving conveyor for a short distance when necessary, thereby invalidating the indicated limits.

Because of these reasons the uniformity principle and the capacity constraint are much more significant than the speed rule. While in the general conveyor operation problem, when computer simulation methods are used to search for workable conveyor speeds, the limits indicated by the speed rule may logically be used as initial trial speeds, it is really not essential to do so. In the design problem, it has been found convenient to disregard the speed rule in the design procedures until after a solution is found, and then apply it merely as a safety measure to check on the feasibility of the suggested speed.

METHOD FOR DETERMINING CONVEYOR CAPACITY REQUIREMENTS

Total requirements for accommodation on the conveyor, as has been noted, may be taken as the sum of the reserve requirements and the operating requirements. Since total reserve capacity to be provided is assumed to be one of the given data, its conversion into reserve capacity requirements in the dynamic sense is readily accomplished, through an application of the principle of conveyor operation, by dividing the total by the revolution time chosen for study.

To get the operating capacity requirements a numeri-

cal method which is simple enough to be carried out on paper has to be used. A detailed description of the method may be found in (3). The numerical example given in a later section may also help illustrate the computational steps. Only a brief account of the method is given here for the sake of completeness. First, the revolution time of the conveyor is assigned a numerical value. Then the loading-unloading schedule, here written in the form of a schedule of algebraic accumulation rates, is broken up into segments, each of which has a length equal to the revolution time chosen for study. The cumulative sums of the corresponding elements in the segments are taken from segment to segment. The operating capacity requirements, on a per unit time basis, may then be taken as the span from the negative peak to the positive peak of these cumulative sums, modified by a correction factor which may at times be neglected.

When this method of determining the operating capacity requirements is used, the total capacity requirements at a given revolution time may be found from the following expression:

K = (total reserve capacity to be provided)/W
+ (per-unit-time operating capacity requirements as determined by the numerical method)
+ 2 (loading rate or unloading rate, whichever is lower) Eq. 5.

The last term in this expression is the correction term mentioned previously. It corrects for the fact that the numerical method assumes, for convenience, that the loading and unloading points are located at the same point. Roughly speaking, half of this correction quantity is to be accommodations for the temporary extra load on the delivery portion of the conveyor, and half of it is to accommodate a stock that is necessary to enable unloading to be started on time. When the total reserve capacity provided is sufficiently large, the correction term may generally be neglected. Empirical studies may also suggest other more acceptable modifications.

DESIGN PROCEDURES

Because of the fact that the total capacity requirements cannot be determined unless a particular revolution time is chosen for the conveyor, and that there are ordinarily many equally feasible revolution times to choose from, the design procedure necessarily has to be of a trial-and-error nature. Briefly, the steps will be in this order: From the given elementary loading-unloading cycle, the workable revolution times are determined by an application of the uniformity principle. For any workable revolution time thus determined, the expected operating capacity requirements are determined by the numerical method. This, together with the given total reserve capacity requirements, determines the capacity requirements through the capacity constraint. Conditions of the actual design situation will then suggest themselves in restricting the choices of conveyor parameters. Finally, when several solutions are possible, some optimality criterion such as cost consideration may be applied to select one of them.

Now Eq. 3. relates the parameters of the conveyor to the capacity requirements. In the design problem the equality sign will suffice. Since it will frequently be referred to later, let it be thus restated and redesignated as follows:

(K) $\qquad K = mqv/L = mq/W = qv/s$

To this expression, let the following definitions be added for convenience.

(W) Revolution time $= W = L/v$
(S) Spacing of carriers $= s = L/m$

For a given elementary loading-unloading cycle and a chosen workable revolution time, there are five parameters of the conveyor to be determined. They are the total number of carriers m, the carrier capacity or the number of parts a carrier can accommodate q, the speed of the conveyor v, the total length of the conveyor L, and the spacing of the carriers s. These *five* parameters must satisfy the *three* conditions as given by expressions K, W, and S. (More precisely, there are six parameters. The sixth one is the revolution time; but it is a known parameter by assumption.) The system is thus underdetermined and two parameters can be chosen *at will*. The actual design situation may happen to impose a constraining condition such as the constraint that carrier spacing must be four feet from center to center. Then, of course, only one parameter can be chosen at will; the rest will be automatically determined by the above expressions. In any case, the *number of imposed* constraints either by specification or by choice *cannot be more than two*.

There are altogether eight possible ways in which two of the parameters can be chosen at will *after* having chosen a value for W. These are:

(s-L) Spacing and length.
(s-m) Spacing and total number of carriers.
(s-v) Spacing and speed of conveyor.
(s-q) Spacing and total carrier capacity.
(q-L) Carrier capacity and total length of conveyor.
(q-v) Carrier capacity and speed of conveyor.
(m-L) Total number of carriers and total length of conveyor.
(m-v) Total number of carriers and speed of conveyor.

In general the conveyor is designed to carry a specified kind of part of material supply. This almost automatically determines the proper carrier spacing that should be used. The situation is then one of the first four cases; that is, only one of the four parameters—length, number of carriers, speed of conveyor, or carrier capac-

TABLE 1

Design Procedure for Some Selected Situations

Case	For given	Find immediately, from	CHOOSE arbitrarily	Thus also choosing, from	Now determine from
$(s\text{-}L)$	s		L	v (W) m (S)	q (K)
$(s\text{-}m)$	s		m	L (S) v (W)	q (K)
$(s\text{-}v)$				L (W) m (S)	q (K)
$(s\text{-}q)$	s		q	v (K)	L (W) m (S)
$(q\text{-}L)$	q	m (K)	L	v (W)	s (S)
$(q\text{-}v)$	q	m (K)	v	L (W)	s (S)
$(m\text{-}L)$	m	q (K)	L	v (W)	s (S)
$(m\text{-}v)$	m	q (K)	v	L (W)	s (S)

ity may be chosen at will. Sometimes it may happen that the carrier capacity q is predetermined or that the total number of carriers m is predetermined. Then again, in either case, only one parameter can be chosen at will; this time, however, it will have to be either the speed or the total length of the conveyor.

The more common cases and their design procedures are given in the form of Table 1. The procedures for other cases should be obvious once the principle is grasped. However, note that predetermining *both* L and v determines W also. This W may or may not be workable. If it is, the design can be completed by arbitrarily choosing one more parameter. Note also that predetermining *both* m and q determines also the total static conveyor capacity. The situation is then more like that in an operation problem, and it may not be possible to find a workable W.

To fix ideas, consider the first situation in Table 1, the case of $(s\text{-}L)$. Here the spacing of the carriers is already predetermined. Hence only one parameter can be chosen at will. In this case, it happens to be the total length of the conveyor. The steps in the design work run as follows:

1. From the given information on the elementary loading-unloading cycle, determine several workable revolution times by means of Eq. 1. and Eq. 2.
2. Decide on a workable revolution time and work out the maximum operating capacity requirements on a per-unit basis by the numerical method. Note that this will be equal to the sum of the most positive peak and the most negative peak for the unit time interval.
3. Choose a likely length for the conveyor. Note that this length would naturally have to be at least twice the shortest distance from the loading point to the unloading point.
4. Find the conveyor speed to be used from expression (W) from the revolution time already decided and the conveyor length just chosen.
5. Find the total number of carriers on the conveyor from expression (S) from the predetermined carrier spacing and the total conveyor length just chosen.
6. Convert the given predetermined maximum reserve capacity requirements into a per-unit-time basis by dividing it by the chosen revolution time.
7. Find the total capacity requirements on a per-unit-time basis by adding together the expected operating capacity requirements given, the predetermined maximum reserve capacity requirements, and twice the smaller of the two rates. This is the value for K.
8. Find the total number of parts each carrier can accommodate from expression (K) from all these known parameters.

Several important points must be carefully noted. First of all, the choices must be guided by technological feasibility and good common-sense experience. For instance, it has already been noted that there is a lower limit to the length of the conveyor. There is also an upper limit to the speed of the conveyor. Secondly, if everything works out satisfactorily, the values thus arrived at represent *only one possible* design out of many. This is the design for the chosen revolution time and the chosen conveyor length. For the same chosen revolution time several conveyor lengths may be chosen. Then, of course, other workable revolution times could be tried with these assumed conveyor lengths. The decision on the final combination to be used rests on many considerations, among them of course, is cost. Cost information is definitely necessary. This, however, is outside of the scope of this article. Therefore, in brief, the following steps should also be added:

9. Compute the associated costs for this design.
10. Assume different conveyor lengths and repeat all the steps from Step. 3.
11. Repeat the same for different workable revolution times.
12. Make a recommendation as to the final choice from relevant practical considerations.

SIMPLE ILLUSTRATIVE EXAMPLE

Suppose the following information on a fictitious production situation shown in Figure 2 is given:

1. Output of feeding area, area A, is six parts per minute.
2. Input of fed area, area B, is two parts per minute.
3. This distance from area A to area B is 1,200 feet, loading point to unloading point.
4. Carrier spacing of four feet center to center is to be used.
5. Reserve capacity (including both stock and space) requirement is to be 480.

The problem is to design an irreversible loop-type conveyor to connect the two areas.

First of all, the elementary loading-unloading cycle must be constructed. Suppose that economic lot size considerations indicate that to sustain continuous consumption in area B, area A should produce in batches of 720 parts, i.e., a production run of 120 minutes or two hours. Then the elementary loading-unloading cycle (which is the same as the output-A-input-B schedule) will be as

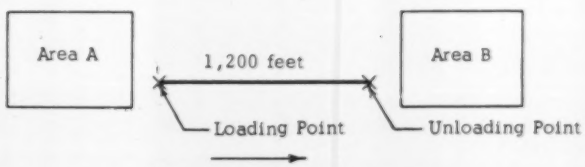

FIG. 2. Fictitious Example.

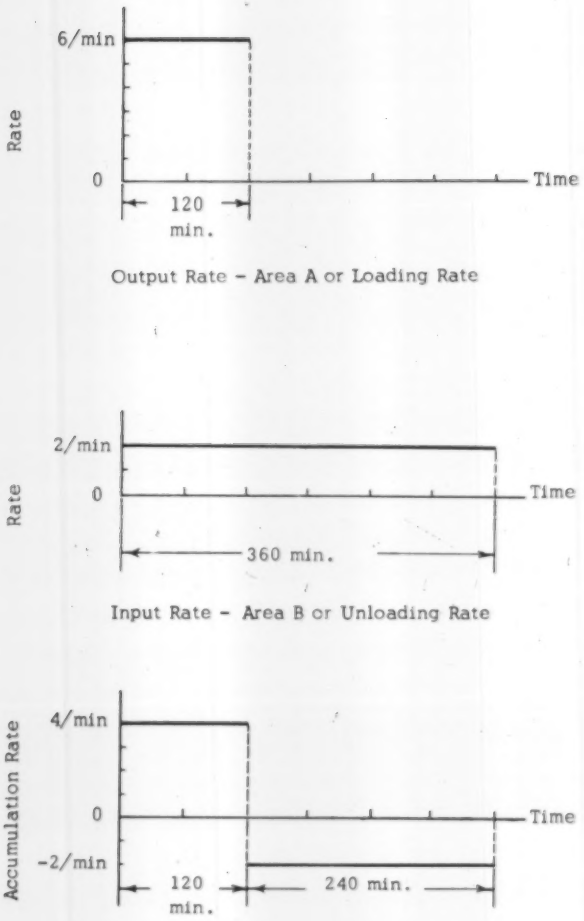

FIG. 3. Fictitious Example.

shown in Figure 3 with a cycle period of 360 minutes or six hours.

Since the given situation fits pretty closely in $(s\text{-}L)$ design situation in Table 1, the design procedure described in the previous section will be followed.

Step 1—the workable revolution times are determined. Suppose for simplicity and clarity of illustration, it is sufficient to study only the duration of one cycle. That is to say, the workable revolution time must necessarily be less than 360 minutes. Then

Eq. 1. and Eq. 2. $N_T = 1$, $T = 360$, $T_L = 120$, and $T_U = 240$.

Eq. 1. becomes $N_W W = 360$ minutes.

$N_W = 2, 3, 4, \cdots$; integer.

Eq. 2. becomes $\dfrac{120}{W} = \text{integer}$, or $\dfrac{240}{W} = \text{integer}$.

Obviously, the values of W that will satisfy both expressions jointly are 120, 60, 40, 30, 24, 20, 15, 12, 10, 8, 5, 4, 3, 2, 1.

Step 2—as the distance between the two areas is given to be 1,200 feet, the values for W less than 40 minutes need not be considered because that would require a conveyor speed that is technologically not feasible or dangerous (twice the minimum distance divided by 40 gives a speed of 60 feet per minute). To make matters simple, let 60 be the chosen workable revolution time.

The determination of the operating capacity requirement for the chosen revolution time of 60 minutes can be done by the numerical method. The computation can be simplified considerably by using a large unit time interval, say, an interval of 30 minutes. The loading rate then becomes $30 \times 6 = 180$ per 30 minutes, the unloading rate becomes $30 \times 2 = 60$ per 30 minutes, and the accumulation rate becomes $30 \times (6-2) = 120$ per 30 minutes for four 30-minute intervals and $30 \times (-2) = -60$ per 30 minutes for eight 30-minute intervals. The elementary loading-unloading cycle now looks like what is shown in Figure 4.

The calculation for the capacity requirement is indicated by Table 2. It is seen that the peak accumulation can be expected to reach 240 in a 30-minute interval. That is, the peak accumulation can be expected to reach $240/30 = 8$ in a one-minute interval. This is also the range of the operating capacity requirements on a per-minute basis.

Step 3—the distance between the loading point and the unloading point is given to be 1,200 feet. The minimum length of the conveyor loop, therefore, would have to be twice this long. This is 2,400 feet. As a first try, let this be the value of the total length.

Step 4—as a result of the chosen revolution time of 60 minutes and the chosen conveyor length of 2,400 feet, the conveyor speed is immediately fixed by expression (W) at $L/W = 2{,}400/60 = 40$ feet per minute. This is a reasonable practical figure.

Step 5—from the given predetermined conveyor spacing of four feet and the chosen conveyor length of 2,400 feet, the total number of carriers on the conveyor is fixed by expression (S) at $m = L/s = 2{,}400/4 = 600$ carriers.

Step 6—the predetermined maximum reserve capacity requirements when converted to a one-minute interval basis, are $480/60 = 8$.

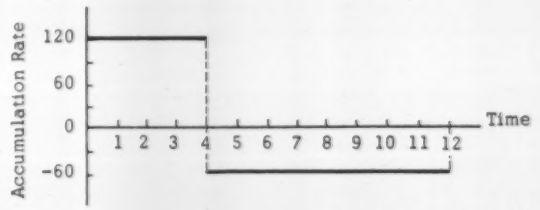

FIG. 4. Converted Elementary Loading-Unloading Cycle for Fictitious Example.

Step 7—the total capacity requirements on a per-minute interval basis are the sum of the maximum operating capacity requirements, the predetermined reserve capacity requirements, and twice the smaller of the two rates. This is $K = 8 + 8 + 4 = 20$.

Step 8—thus the total number of parts each carrier is to accommodate is, from expression (K), $q = KW/m = 20 \times 60/600 = 2$ parts per carrier. This seems to be a practically feasible number, provided of course that the size of the part is not excessively large nor excessively small. This completes the design of the conveyor. The parameters of the conveyor are $W = 60$ minutes, $T = 360$ minutes, $L = 2{,}400$ feet, $m = 600$, $q = 2$, $s = 4$ feet, and $v = 40$ feet/minute.

TABLE 2

Calculations for Capacity Requirement

Revolution	Accumulation Rate		Accumulation	
Interval	1	2	1	2
1	120	120	120	120
2	120	120	240	240
3	−60	−60	180	180
4	−60	−60	120	120
5	−60	−60	60	60
6	−60	−60	0	0

Step 9—from given cost information compute the associated costs for this design.

The same procedure can now be followed from other selected combinations of revolution time and conveyor length. When several alternative designs are available, the design to be used can be selected by cost or other relevant considerations.

As indicated previously, before finally passing a design as a feasible design, it would be a good practice to check the speed called for by the length to see if it is within the limits specified by the speed rule. Of course, the designer might choose to apply this restrictive relationship, the speed rule, earlier in the design work to help him narrow down the number of alternative values for his parameters. That may sometimes be advisable also.

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Program Loading

by **M. E. BRONSON**

Link Division, General Precision, Inc.

THE PROBLEM of maintaining accurate, up-to-date shop load forecasts, especially for larger companies, continues to be a time-consuming headache even with the advent of IBM tabulation. Such forecasts, if properly maintained, can be of invaluable assistance to the management of any company interested in preserving its economic well-being. Good forecasts:

1. Lead to intelligent personnel policies, because they forewarn management of the necessity to expand or reduce the labor force.
2. Provide a basis for scheduling new work, for averting schedule slippage, and for planning overtime, second shift, or subcontract remedial measures.
3. Serve as a tool for projecting overhead and for gearing indirect labor requirements to optimal levels.

In the interest of encouraging better and faster shop load forecasts, this presentation describes a new concept in data projection called program loading, which combines the advantageous features of both the manual and the IBM tabulation methods, and which is easily implemented with the aid of an LGP-30 (or some similar) digital computer.

PROGRAM LOADING

Program loading is a mathematical system which can best be applied to the long-range manpower loading of job shop industries geared to a multi-project operation of a complex nature. The inputs to the system are derived from the project budgets and schedules, which are the two prime variables of any load forecasting system. The processing agent is a digital computer, on which the basic program is stored. The output of the system is a monthly load by department, projected for a period of twelve months.

Some of the benefits to be dervied from program loading are:

1. It eliminates tedious hand calculations, thus reducing probability of error.
2. The advantage of speed is realized. New forcasts can be obtained in a matter of hours compared to the minimum of three weeks previously required.
3. The computer program is, in effect, an analog of the production system, and as such can be used to simulate the effects of schedule changes on production departments. This simulation ability coupled with the speed of the computer makes it possible to schedule future work with an *a priori* knowledge of its effect on the production load.

The factors which enter into shop loading and which

* Thanks are due to C. W. Lundstrom, W. G. Grady, Jr., and R. J. Bibbons of the Link Division for their assistance.

have direct bearing on the complexity of the task are the number of active contracts in the shops, their stage of development in engineering, and the capacities of the production shops in terms of facilities and manpower. These factors are prime. Maintaining a load forecast to even minimal expectations requires that the following operations be performed on a monthly basis.

1. The hours expended in each department for each contract must be compiled.
2. A percent complete for each department must be determined. This is based on the knowledge of what work has been released to the shop and its stage of completion, as determined by move tickets and completed work travelers.
3. The hours expended the previous month must be calculated for each item to check both the accuracy of the load and the probable rate of expenditure for succeeding months.
4. The monthly departmental expenditures for each project must be projected. Depending on the number of fabrication, assembly and inspection departments involved, multiplied by the number of active and potentially active contracts, this task can be formidable as indicated in the typical load forecast shown in Figure 1.

At Link, previous attempts have been made to mechanize shop loading by programming as many operations as possible on IBM tabulating equipment. Because of the dynamic condition of the load and the relative slowness of such equipment, however, the results were only partially successful. Briefly, the system operated as follows:

Departmental loads for each contract were tabulated and punched into IBM cards. The load spread in percent was calculated for the life of the department load and punched into another series of IBM cards. As long as the load remained constant and was expended in the predetermined manner the system worked fine, but as soon as the load varied, or slippage was introduced, the entire spread had to be recalculated. Other complications were inherent in the system, e.g. the tendency to overcorrect when recalcuating either the load or the percent spread. The system did provide a direct comparison of actual hour expenditures versus anticipated expenditures, which was excellent, but the projection was by department only, not by contract within departments.

As we have said, the system outlined in this article (using a digital computer) combines the advantageous features of both the hand prepared load forecast and the IBM tabulated forecast. In devising the system, the following criteria were established as being necessary prerequisites:

1. A minimum of maintenance should be required. This implies that the system should be self-correcting in so far as possible.
2. An accurate indication of what has to be done to meet schedule should be provided.
3. It should be possible to run a revised forecast at any time, even if only to run "trial" programs. Comparative information should be available in a matter of hours, not weeks.
4. The system should eliminate areas which are susceptible to human error.

An analysis of previous departmental load patterns taken from a variety of projects over a considerable span of time indicates that a fairly typical curve is generated regardless of the departmental function. As might be expected, the curve closely approximates a normal curve, skewed in some instances and in varying degrees to the right (Figure 2). Reasons for the curve-shape are quite apparent and directly attributable to the nature of a multi-project operation. The load for any given project

Dept. No. 161		Load Forecast											
		1960						1961					
Project	Budget	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
AF 100	7700	1540	1216	770	325	162	15						
101	15,500	1556	2810	3655	3570	2760	1473	655	380	170	65		
102	8750	390	266	110	55	5							
103	11,975			119	338	970	1863	2365	2482	1711	1457	960	525
104	1430	15	65	120	275	425	300	160	55	10	5		
105	4100	310	72	33									
106	20,600			110	390	1130	1870	2570	3030	3100	2262	1428	765
107	17,200					35	168	490	866	1370	2050	2120	1975
108	9200	1870	1456	980	415	189	72	15					
109	5500		86	114	370	930	1325	1175	850	325	175	80	30
110	6030									110	395	880	1270
NA 200	8600	210	890	1730	2570	2300	600	280	10				
201	14,320	1170	760	350	115	60							
202	6000					110	670	1030	1490	1655	845	175	25
203	7580							87	266	390	870	1430	1900
CO 300	3870	560	190	60	10								
301	16,600							360	890	1670	2280	2810	2950
302	8400									115	405	930	1775
303	2100	970	315	115	35								
SC 400	1470	95	28	12	2								
401	680	106	38	8									
402	10,085		175	425	850	1210	1690	1700	1750	1250	710	220	105
Total		8790	8367	8711	9320	10,286	10,046	10,887	12,069	11,876	11,519	11,033	11,320

FIG. 1

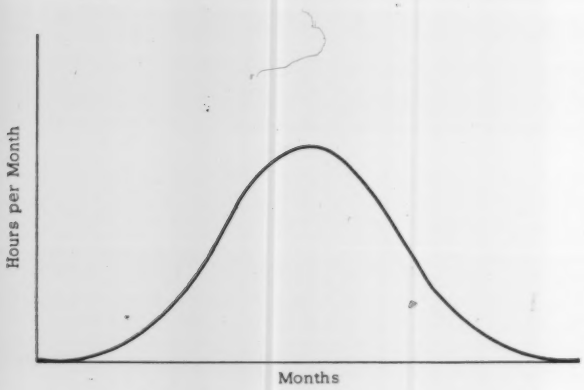


FIG. 2

must be phased into the production cycle as facilities are made available from projects nearing completion. As the load peaks and begins to taper off, late design releases and engineering changes begin to introduce skewing, the degree of skewing being dependent on the lateness of the releases and the quantity of the changes.

By plotting the cumulative expenditures in percent, we arrive at a curve similar to that shown in Figure 3. This curve is programmed into the digital computer and provides the basis for all subsequent machine operations. Variations in the life of a particular load or variations in the percent complete will stretch or compress the curve as necessary to meet the desired schedule.

We have, then, three independent variables with regard to the curve: load, load life, and percent complete. Two simple but representative examples are depicted in the following section to lend graphical description to the system.

LOADING THE COMPUTER (GENERAL)

1. Determine the departmental loads. These are based on the bid figure generated by Industrial Engineering.
2. Determine start and end dates. These are established by Production Control and are based on delivery commitments.
3. Insert steps 1 and 2 into the computer and repeat them for each project.
4. Periodically determine, from the cost analysis, expenditures to date.
5. Compare item 4 with the budgeted hours and determine the percent complete.
6. Compare item 5 with the programmed expenditures and determine whether a correction is required.
7. Insert the change in the computer.

The computer can easily be programmed to handle steps 5, 6, and 7 if it is so desired. The only prerequisite for this is a tabular listing of cumulative expenditures by department.

SOLUTION PROCEDURE

Example 1: Correcting for Load Slippage (Figures 4 and 5)

From step 5 it is determined that the percent complete is 43%. Assuming that we are in the third month of the program and, further, that the end date has not slipped, then the remaining load must be spread over the three months yet to go. From the general solution shown in the appendix we arrive at:

$$T_0 = 43\%$$
$$U_0 = 5.4$$
$$\text{Life} = 3$$
$$L = \text{Load}$$

For the fourth month:

$$U_i = U_1 = \frac{12M_1 + U_0(\text{Life} - M_1)}{\text{Life}}$$

$$U_1 = \frac{12 \times 1 + 5.4(3 - 1)}{3}$$

$$= 7.6$$

Therefore:

$$T_1 = 75\%$$

Then:

$$\Delta T = T_1 - T_0$$
$$= 75\% - 43\%$$
$$= 32\%$$

The load for the fourth month is then .32 L.
Solving U_i for the fifth month:

$$U_2 = \frac{12 \times M_2 + U_0(\text{Life} - M_2)}{\text{Life}}$$

$$= \frac{12 \times 2 + 5.4(3 - 2)}{3}$$

$$U_2 = 9.8$$
$$T_2 = 94\%$$

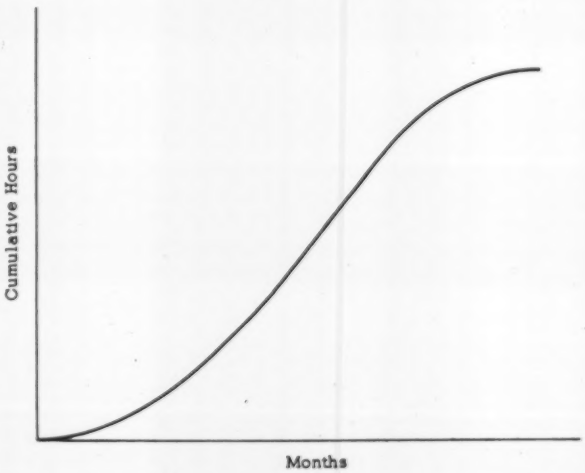


FIG. 3

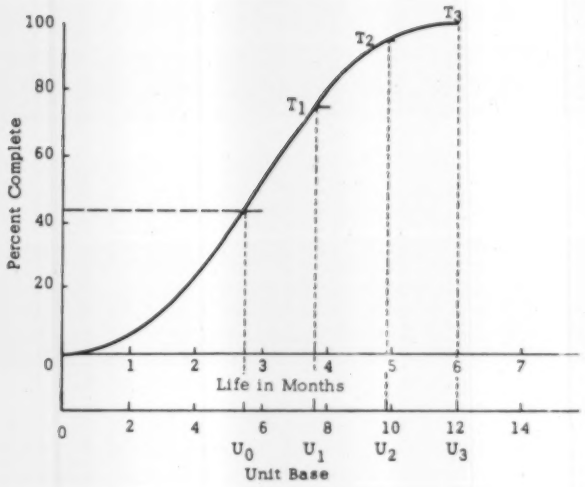


FIG. 4

$$T = T_2 - T_{(2-1)}$$
$$= 94\% - 75\%$$
$$= 19\%$$

Therefore the load for the fifth month is $.19L$. Solving U_i for the sixth month:

$$U_3 = \frac{12 \times 3 + 5.4(3 - 3)}{3}$$
$$= 12$$
$$T_3 = 100\%$$
$$T = 100\% - 94\%$$
$$= 6\%$$

Hence the load for the sixth month is $.06L$.

The corrected progress is illustrated by dash line in Figure 5. The importance of the unit base included in the initial program becomes evident at this time. In essence, it provides the computer with the comparative informaton necessary to recognize and reprogram a change in schedule. The selection of a base is entirely arbitrary, since for all practical purposes we have an infinite series of points.

Example 2: Correcting for Schedule Slippage (Figures 6 and 7)

Schedule slippage may occur for a variety of reasons; for illustrative purposes let us assume simply that it has. Using the program of the previous example, we determine at the third month that this load must be slipped two months, so that the total life is now 8 months, 5 months of which are remaining.

$$T_0 = 43\%$$
$$U_0 = 5.4$$
$$\text{Life} = 5$$
$$L = \text{Load}$$

Following the same general procedure as before, we arrive at:

$$U_1 = 6.73$$
$$U_2 = 8.04$$
$$U_3 = 9.36$$
$$U_4 = 10.68$$
$$U_5 = 12$$

Therefore:

$$T_1 = 63\% \ \& \ \Delta T = 20\%$$
$$T_2 = 82\% \ \& \ \Delta T = 19\%$$
$$T_3 = 92\% \ \& \ \Delta T = 10\%$$
$$T_4 = 98.5\% \ \& \ \Delta T = 6.5\%$$
$$T_5 = 100\% \ \& \ \Delta T = 1.5\%$$

Then the load for each of the succeeding 5 months must be $.20L$, $.19L$, $.10L$, $.065L$, and $.015L$, respectively. The corrected progress is illustrated by dash line in Figure 7.

SUMMARY

The study outlined in this article was concerned with the applicability of computer simulation to the problem of forecasting shop loads. It provides a rapid means of evaluating the multiplicity of schedule and load alternatives open to management, and the effect of these alternatives on personnel and facility utilization. The possibility of expanding this laboratory approach to project load by machine group, to provide decision rules for inventory control, to examine more closely the details of flow rates, factory layout, and service demands, is inherent in the system. Continued use of the system should provide a much better understanding of the behavior of a job shop production system, and in all likelihood a much better and broader insight into the use of a digital computer as a simulation device for program loading.

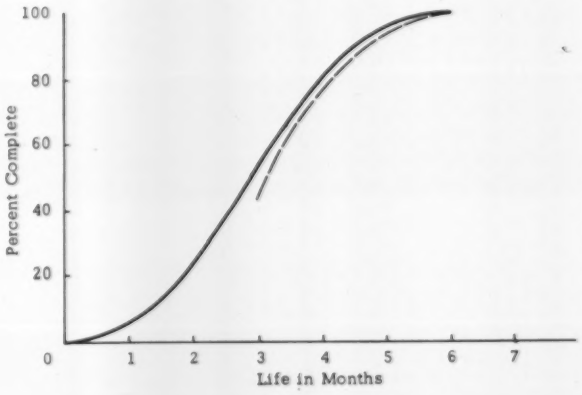


FIG. 5

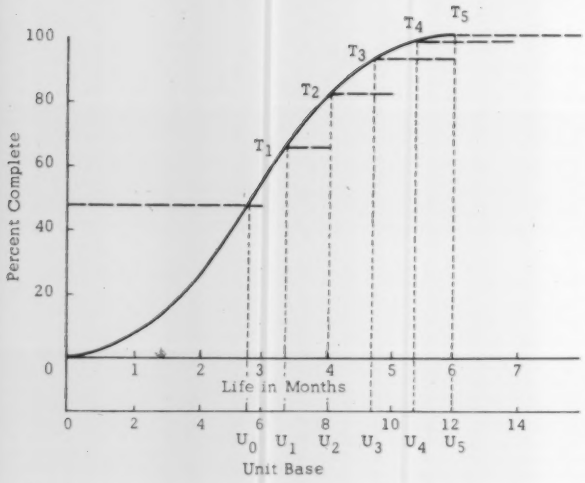


FIG. 6

APPENDIX

Problem: To determine departmental loads by month and by project.

Given: 1. Department load by project. 2. Percent of Total Time completed. 3. Life

Solution: 1. Call the percent time completed T_0.

2. Take the percent of load actually completed and determine by interpolation the unit value at which it appears. Call this unit U_0. (See Figures 4 and 6).

3. Let U_i equal the unit value for the "ith" month and solve U_i for each of the succeeding months, letting the succeeding months be designated by M_i.

$$i = 1, 2, 3 \cdots n$$

4. Let X_i equal the distance from U_0 to the "ith" unit.

5. Then $X_i = U_i - U_0$

and

$$\frac{\text{Life}}{(12 - U_0)} = \frac{M_i}{X_i}$$

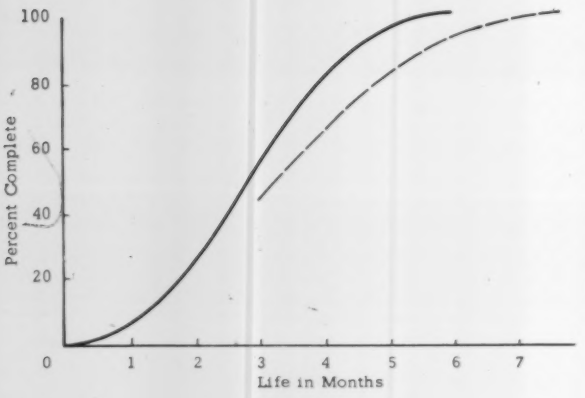


FIG. 7

$$X_i = \frac{M_i(12 - U_0)}{\text{Life}}$$

$$U_i = \frac{M_i(12 - U_0)}{\text{Life}} + U_0$$

$$U_i = \frac{M_i(12 - U_0) + U_0(\text{Life})}{\text{Life}}$$

$$\boxed{U_i = \frac{12M_i + U_0(\text{Life} - M_i)}{\text{Life}}}$$

6. Obtain by interpolation the percent of load expended for U_i and call this T_i. (See Figures 4 and 6.)

7. Subtract from T_i the percent completed up to the previous month.

$$T_i - T_{(i-1)} = \Delta T_i$$

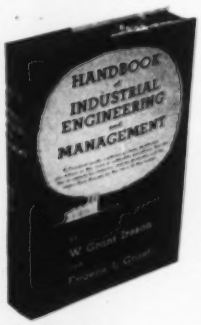
8. Multiply ΔT_i by the total load (L) for this project

$$\Delta T_i L = L_i$$

where L_i = load for the "ith" month.

HANDBOOK

Industrial Engineering AND Management



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Procedures for Forecasting Aircraft Engine Maintenance Removal Quantities

by WILLIAM W. HINES *and* JOSEPH J. MODER

School of Industrial Engineering, Georgia Institute of Technology

THIS presentation is concerned with the determination and application of maintenance removal rates of aircraft engines, for use in a forecasting routine designed to predict removal quantities on which overhaul schedules are dependent. These problems are treated in two parts. Part I deals with the collection of the data and development of engine removal rates as a function of the flying hours on the engine. Part II deals with the utilization of these rates to forecast removals for a specified set of engines and flying schedule. Finally, a comparison is made of these forecasts with those developed by present commercial airline methods, and the values actually experienced during the forecast period.

PART I

This study is concerned with the design of a method for forecasting overhaul removal quantities of aircraft engines for a commercial airline. Because of the high cost of modern aircraft, accurate forecasting of engine maintenance has become an important factor in balancing the number of spare engines and the size of the maintenance facilities to minimize total relevant operating costs. The specific engines studied, which cost approximately $100,000 each, are the type R-3350 used in the DC-7 airliner. The future importance of this problem is brought out by the $250,000 cost of one engine assembly type J-57 used in the jet airliner.

Consider the "engine pipeline" of Figure 1. Installed engines at (A) are actively engaged in the flying program. Engines are removed for maintenance for two primary reasons, either because they have reached maximum allowable operating time, which is established by the Civil Aeronautics Administration (CAA), or because they have some type of malfunction. All removals are inspected at (B). The maximum-time removals are automatically put into major overhaul maintenance (D). Engines removed because of malfunction before reaching the maximum allowable operating time are sorted according to the seriousness of the malfunction. If the difficulty is minor in nature, the engines are sent to hospital maintenance (C), otherwise they go into major overhaul maintenance (D).

Engines going into hospital maintenance will be called hospital removals; engines other than maximum-time removals going into major overhaul maintenance will be called failure removals. There are thus three categories of removals: hospital, failure, and time removals. Hospital maintenance is a minor repair type of maintenance which does not necessitate complete disassembly. The time since overhaul (TSO) on an engine leaving hospital maintenance is the same as when the engine entered hospital maintenance. Failure and time removals both receive the same major overhaul maintenance, consisting of complete disassembly, inspection of each component part, replacement of worn parts, reassembly, and test. An engine leaving major overhaul is considered equivalent to a new engine and is given a zero TSO.

This maintenance cycle can be depicted as a queueing problem, as shown in Figure 2. The economic design problem presented here is to select the minimum total-relevant-cost set of parameters S_o, μ_o, S_h, μ_h, and N, for a given set of arrival rates λ_o, and λ_h, which will hold the engine shortage probability to an acceptably low level. This latter probability might be based on a rate which the CAA would tolerate for granting maintenance exceptions. The purpose of this article is to present methods of forecasting λ_o and λ_h, considering such factors as the number and age of the engines in the system.[1]

The inventory from which the data in this study were taken was a constantly changing inventory. Some engines had received as many as ten overhauls while recent acquisitions had received none. Since this situation is similar to that with which an actuary deals in studying deaths by age groups, the problem was approached from the point of view of developing a mortality rate or engine removal rate function.

In 1950 the U. S. Air Force started working towards engine life analysis using some of the principles of actuarial science. By 1954 the method had been developed to a point where an expected life value, called the Engine Life Expectancy, was periodically calculated for each

[1] A partial solution to this queueing problem was presented at the Fourteenth National Meeting of ORSA by Lewis Brotman, Hughes Aircraft Company, Culver City, California, in a paper entitled "An Analysis of Parameters which Affect Readiness Probability."

type engine, and these values were used in planning and forecasting for future programs. Air Force work in this area is explained in a USAF Technical Order, which outlines some of the methods used in the development of the present study (3).

DEVELOPMENT OF REMOVAL RATES

This study covered a period of 46 consecutive months, starting with the receipt of the first engine in 1954 and included a total of 105 engines. Some of these engines were received on aircraft and some were received to be used as spares. Failure and hospital removals were classified according to age interval, based on the engine TSO at the time of removal. An age interval width of 20 hours was used in the study; since the maximum operating time for the particular engines considered is 1200 hours, a total of 60 such age intervals are possible—viz., 0-20, 20-40, . . . 1180-1200.

Reference to the age interval of the engine at the time of removal, the month of the study, and the specific engine in question will be made as follows:

Factor	*Reference*	*Domain of Subscript Reference*
Age Interval	i	1, 2, . . . , 60
Month of the Study	j	1, 2, . . . , 46
Engine Number	k	1, 2, . . . , 105

The symbol F_{ijk} will denote the occurrence or non-occurrence of a failure removal, during the jth month, for the kth engine, whose TSO placed it in the ith age interval. The two possible conditions are given by:

$F_{ijk} = 1$ (failure removal did occur)

$F_{ijk} = 0$ (failure removal did not occur)

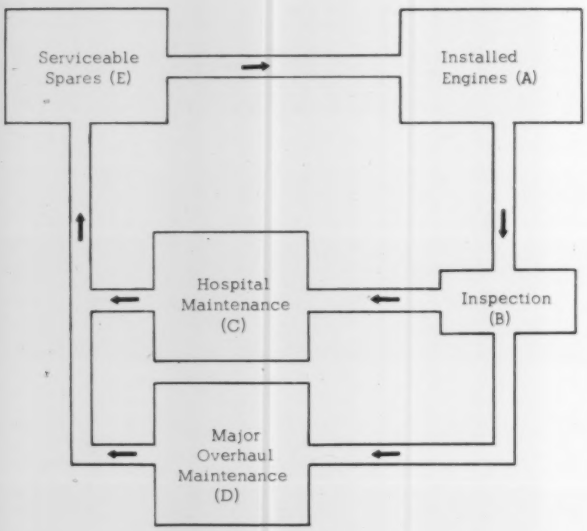


FIG. 1. The Commercial Airlines' "Engine Pipeline."

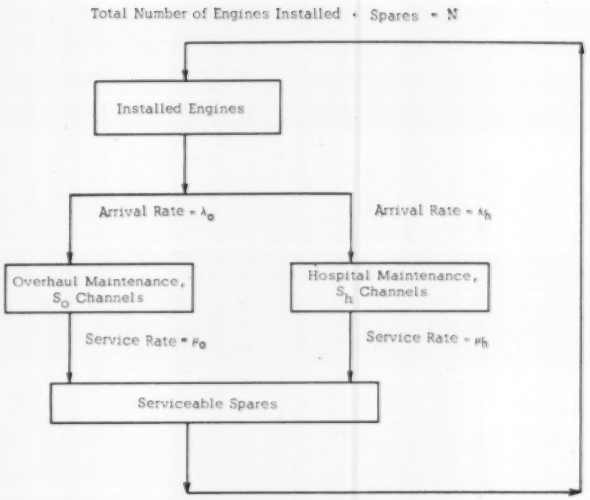

Total Number of Engines Installed + Spares = N
Installed Engines
Arrival Rate = λ_o
Arrival Rate = λ_h
Overhaul Maintenance, S_o Channels
Hospital Maintenance, S_h Channels
Service Rate = μ_o
Service Rate = μ_h
Serviceable Spares

FIG. 2. Queueing Approach to the Flow of Commercial Aircraft Engines.

The data in this study are then summarized as follows:

$F_{ij.} = \sum_{k=1}^{105} F_{ijk}$ = total number of failure removals occurring during the jth month for engines whose TSO at the time of removal placed them in the ith age interval.

$F_{i..} = \sum_{j=1}^{46} F_{ij.}$ = total number of failure removals during the entire 46-month study period for engines whose TSO at the time of removal placed them in the ith age interval.

H_{ijk}, $H_{ij.}$, *and* $H_{i..}$ are similarly defined for hospital removals.

To evaluate the removals, the flying hours on the engines have been summarized as follows:

P_{ijk} = number of hours that the kth engine, in the ith age interval, was flown during the jth month.

$P_{ij.} = \sum_{k=1}^{105} P_{ijk}$ = total number of engine hours flown during the jth month for all engines in the ith age interval.

$P_{i..} = \sum_{j=1}^{46} P_{ij.}$ = total number of engine hours flown during the entire 46-month study period for all engines in the ith age interval.

A unit of engine exposure is conveniently defined as 20 flying hours, so that

$E_{ijk} = \frac{P_{ijk}}{20}$, and

$E_{i..} = \frac{P_{i..}}{20}$ = total number of units of exposure in the ith age interval, for all engines during this entire study.

Values of $E_{i..}$ along with $F_{i..}$ and $H_{i..}$ are plotted in histogram form in Figure 3.

These summarized data were analyzed by first calculating a set of crude engine-failure rates, f_i', where

$$f_i' = \frac{F_{i..}}{E_{i..}}, \qquad i = 1, 2, 3, \cdots, 59.$$

The units for f_i' are failures per exposure, and f_i' is an estimate of the probability, f_i, that an engine will fail while aging from the beginning of interval i to the beginning of interval $i + 1$. Thus $f_i = f_i' + e_i$, where e_i is the random estimation error. The calculated f_i' values are plotted as a frequency polygon in Figure 4a.

DEVELOPMENT OF PREDICTION EQUATIONS

It is reasonable to hypothesize for equipment of this type that f_i is a function of the age interval i, on the basis of higher infant as well as old-age mortality, compared to the intermediate-age mortality. Two methods of estimating this relationship from the observed f_i' values were tested: an actuarial procedure, and the least-squares method using a polynomial function for the model. There is reason to believe that in the case of engine failure rates, the laws of nature do not exhibit irregular variations, but may be expressed in terms of regular and continuous functions. This conclusion, reached on intuitive grounds, has been supported through the years in many and varied types of experiments.

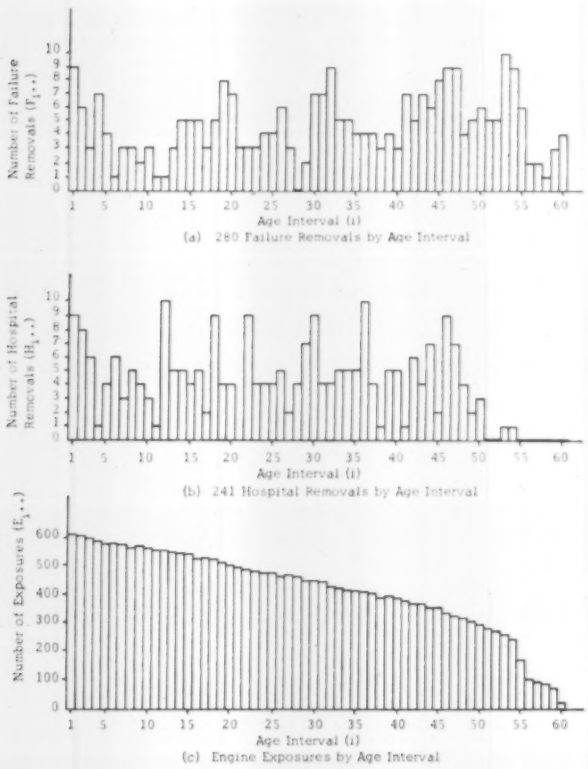

Number of Failure Removals ($F_{i..}$)
Age Interval (i)
(a) 280 Failure Removals by Age Interval
Number of Hospital Removals ($H_{i..}$)
Age Interval (i)
(b) 241 Hospital Removals by Age Interval
Number of Exposures ($E_{i..}$)
Age Interval (i)
(c) Engine Exposures by Age Interval

FIG. 3. Histograms of Failure Removals, Hospital Removals, and Exposures in Each of the 20-Hour Age Intervals.

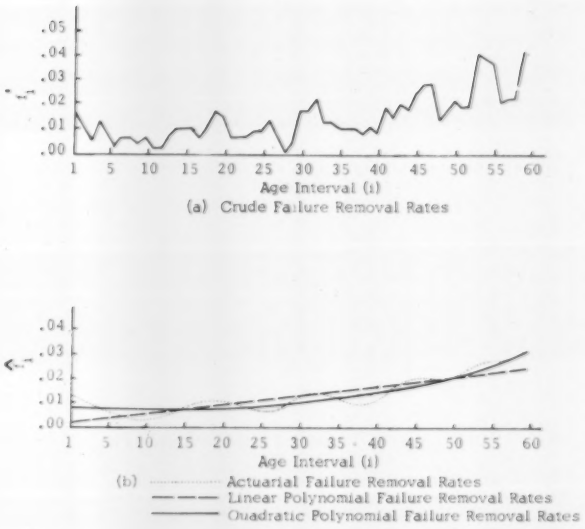

Age Interval (i)
(a) Crude Failure Removal Rates
Age Interval (i)
(b) Actuarial Failure Removal Rates
Linear Polynomial Failure Removal Rates
Quadratic Polynomial Failure Removal Rates

FIG. 4. Engine Failure Rates by Age Interval.

The actuarial procedure used in this problem is called an adjusted-average or linear-compound method. Consider the ith f_i' value; then the corresponding estimate of

$$f_i, \text{ i.e. } \hat{f}_i,$$

is found from the following Eq. 1.:

$$\hat{f}_i = a_8 f_{i-8}' + \cdots + a_1 f_{i-1}' + a_0 f_i' + a_1 f_{i+1}' + \cdots + a_8 f_{i+8}'. \qquad \text{Eq. 1.}$$

The a's listed below were given by Miller (2).

$a_0 = +.1892$	$a_3 = +.0923$	$a_6 = -.0186$
$a_1 = +.1764$	$a_4 = +.0421$	$a_7 = -.0204$
$a_2 = +.1411$	$a_5 = +.0025$	$a_8 = -.0100$

In employing the actuarial method, we let $f_{-7}' = f_{-6}' = \cdots = f_0' = f_1'$ in order to calculate $\hat{f}_1, \hat{f}_2, \hat{f}_3, \cdots \hat{f}_7$; and similarly $f_{67}' = f_{66}' = \cdots = f_{60}' = f_{59}'$ in order to calculate $\hat{f}_{52}, \hat{f}_{53}, \hat{f}_{54}, \cdots, \hat{f}_{59}$. The results of this method, labeled actuarial rates, are shown graphically in Figure 4b.

An assumption underlying the application of linear compound method is that over a limited range, most series of data of this type may be approximated by a polynomial of the third degree. The determination of the values a_i is made subject to such a requirement; the a_i values employed are those which minimize the third difference error subject to this requirement.

The second method employed to obtain an estimate of the f_i values was the method of least squares, with Eq. 2. taken as the mathematical model. Since the variation in the number of exposures ($E_{i..}$), as shown in Figure 3c,

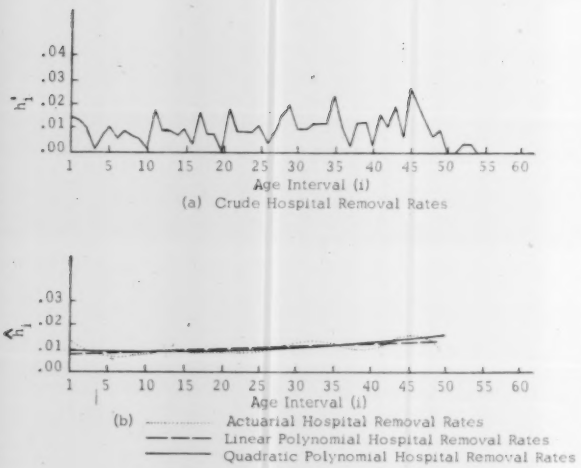


FIG. 5. Hospital Removal Rates by Age Interval.

was not too great, all observed f_i' values were given equal weight.

$$f_i = b_0 + b_1(i) + b_2(i)^2 + b_3(i)^3 + \cdots + e_i. \quad \text{Eq. 2.}$$

This method was employed to give the best-fitting polynomials of degrees one through four. Examination of Figure 4b indicates a considerable difference, as expected in the linear and quadratic fit; however, the deviation of the cubic and quartic polynomials from the quadratic was so slight that their graphs were practically indistinguishable. The last interval, $i = 60$, was not considered in the fitting routines because all engines remaining at the end of interval 59 are removed sometime during interval 60 as time removals; thus

$$\hat{f}_i = f_i = 1 \quad \text{for} \quad i = 60.$$

The constants for the best fitting polynomials are given in Table 1. The IBM 650 computer routine PL05 was used to fit these polynomials and make related calculations. Although the method of orthogonal polynomials is appropriate for fitting these data which are spaced at controlled levels with an equal interval width along the independent variable scale, the use of the PL05 computer routine was still justifiable on an economic basis.

The assumptions underlying the least squares method and the confidence interval statement presented at a later point are:

a. The i values are fixed variates known without error.

b. The expected value of f_i may be expressed as

$$E(f_i) = b_0 + b_1(i) + b_2(i)^2 + b_3(i)^3 + \cdots$$

c. The e_i values in Eq. 2. are normally and independently distributed with mean zero and variance σ_i^2.

d. The variance σ_i^2 is constant over all levels of i.

Assumptions a, b and c appear to be satisfied reasonably well for these data; however, since there are fewer exposures E_i . ., for the larger values of i than for the smaller values, assumption d is not completely satisfied. We did not choose to weight the values f_i' to correct for this condition, thereby sacrificing some efficiency in the fitting process.

Of the two methods studied to fit theoretical functions to these data, the least squares polynomial procedure was selected for purposes of predicting f_i. The analysis

TABLE 1

Least Squares Estimates of the Coefficients in the Polynomial Functions for Estimating f_i. (All values given must be multiplied by 10^{-5}.)

Function	Coefficients				
	b_0	b_1	b_2	b_3	b_4
Linear	185.3	36.38	—	—	—
Quadratic	816.5	−25.71	1.035	—	—
Cubic	885.9	−39.03	1.585	−0.0061	—
Quartic	947.6	−58.17	2.992	−0.0424	0.0003

of variance associated with the fitting of a polynomial regression equation, summarized in Table 2, indicates that a quadratic function is adequate to represent these data. The actuarial procedure was rejected because no theoretical justification could be found for the pronounced oscillatory nature of the actuarial fit, which is an expected result in fitting data by the linear compound method.

The hospital removal rates were treated in the same manner as described above for the failure removals. The results obtained from the seventeen-point smoothing formula, along with the linear and quadratic polynominal equations, are shown in Figure 5b. It will be noted that intervals 1 through 50 are the only intervals considered in the fitting routine, since operational policy is to consider any removal occurring after 1000 hours as a failure

TABLE 2

Analysis of Variance of Regression of Engine Failure Rate on Age Interval

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F Ratio	Significance
Linear	1	0.0022640	0.0022640	65.05	Significant at .001 level
Quadratic	1	0.0004247	0.0004247	12.20	Significant at .001 level
Cubic	1	0.0000033	0.0000033	0.094	Not Significant
Quartic	1	0.0000018	0.0000018	0.052	Not Significant
Residual	54	0.0018798	0.0000348		
Total	58	0.0045736			

TABLE 3

Analysis of Variance of Regression of Engine Hospital Removal Rates on Age Interval

Source	Degrees of Freedom	Sum of Squares	Mean Squares	*F* Ratio	Significance
Linear	1	0.0001512	0.0001512	5.0	Significant at the .05 level
Quadratic	1	0.0000121	0.0000121	0.4	Not Significant
Cubic	1	0.0000367	0.0000367	1.2	Not Significant
Quartic	1	0.0000030	0.0000030	0.1	Not Significant
Residual	45	0.0013696	0.0000304		
Total	49	0.0015726			

removal unless some emergency situation exists.

By a process of elimination, similar to that used above on the failure removals, the linear function shown in Figure 5b was selected for purposes of predicting h_i, the probability (analogous to f_i) that an engine will undergo hospital removal sometime in its ith age interval. The analysis of variance data on which the choice of the linear function was based are given in Table 3.

The estimated variance of the predicted mean failure rate using the quadratic function is given, using matrix notation (1).

$$s_{\hat{f}_i}^2 = s^2(\underline{X}_i' \; A^{-1} \; \underline{X}_i)$$

where

$$\underline{X}_i' = (1 \;\; i \;\; i^2), \qquad \underline{X}_i = \begin{pmatrix} 1 \\ i \\ i^2 \end{pmatrix}$$

s^2 = Residual Error Variance = .0000348, and

$$A = \begin{bmatrix} n & \sum x_1 & \sum x_2 \\ \sum x_1 & \sum x_1^2 & \sum x_1 x_2 \\ \sum x_2 & \sum x_1 x_2 & \sum x_2^2 \end{bmatrix},$$

where

$$x_1 = i \quad \text{and} \quad x_2 = i^2.$$

Then

$$A \doteq \begin{bmatrix} 59.0 & 17.7 \times 10^2 & 70.2 \times 10^3 \\ 17.7 \times 10^2 & 70.2 \times 10^3 & 31.3 \times 10^5 \\ 70.2 \times 10^3 & 31.3 \times 10^5 & 14.9 \times 10^7 \end{bmatrix}$$

and

$$A^{-1} \doteq \begin{bmatrix} 1.6 \times 10^{-1} & -1.1 \times 10^{-2} & 1.5 \times 10^{-4} \\ -1.1 \times 10^{-2} & 9.2 \times 10^{-4} & -1.5 \times 10^{-5} \\ 1.5 \times 10^{-4} & -1.5 \times 10^{-5} & 2.4 \times 10^{-7} \end{bmatrix}.$$

A 90% confidence interval on the predicted mean failure rate is,

$$\hat{f}_i \pm t_{(.10,54)}\, s_{\hat{f}_i}, \quad \text{where} \quad t_{(.10,54)} = 1.68,$$

as read from a table of the Student t distribution.

The estimated standard deviations and approximate confidence intervals are given in Table 4 for $i = 1, 30, 59$.

TABLE 4

Estimated Standard Deviations and Confidence Intervals

i	$s_{\hat{f}_i}$	$\hat{f}_i \pm t_{(.10,54)}\, s_{\hat{f}_i}$
1	0.00223	0.00792 ± .00374
30	0.00115	0.00972 ± .00193
59	0.00223	0.02885 ± .00374

CONCLUSIONS FOR PART I

The function chosen to estimate the probability that an engine will require major overhaul in aging from the beginning of interval i to the beginning of interval $i+1$, is given by $\hat{f}_i$ as follows:

$$\hat{f}_i = 10^{-3}[816 - 25.7(i) + 1.04(i)^2], \quad \text{for } i = 1, 2, \cdots 59;$$
$$\hat{f}_i = 1, \qquad \text{for } i = 60. \qquad \text{Eq. 3.}$$

Similarly, the function chosen for hospital removals is given by h_i as follows:

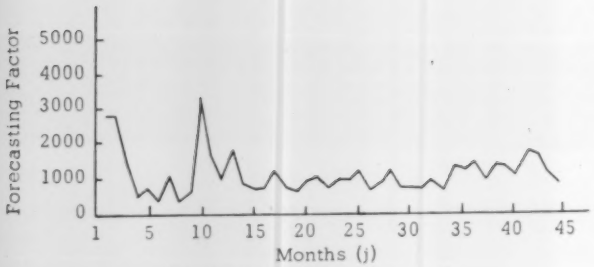
$$\hat{h}_i = 10^{-3}[717 + 12(i)], \quad \text{for } i = 1, 2, \cdots 50;$$
$$\hat{h}_i = 0, \qquad \text{for } i = 51, 52, \cdots, 60. \qquad \text{Eq. 4.}$$

PART II

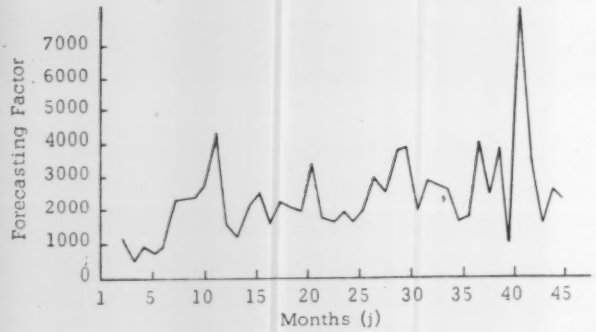
The second portion of this article is concerned with applying the removal rate functions developed in Part I to forecast future maintenance removals. Although the methods described are applicable to hospital as well as major overhaul removals, only the latter will be treated in detail here. The calendar year of 1957 was used for this part of the study.

INVENTORY AGING METHOD

The numbers of installed engines, by age interval, on 1 January 1957 are denoted by $I_i^{(1)}$. The superscript *1* indicates that this is the engine inventory at the start of the first cycle of the forecast period, while the subscript i denotes the engine age interval as determined by the TSO values on each installed engine. This aging process is performed in increments or cycles of 20 hours each, during which the $\hat{f}_i$ values given by Eq. 3. are assumed constant. The superscript *1* on I covers the first 20 hours of this aging process, a superscript *2* covers the second 20 hours, etc., for the entire forecast period. The number of engines in the ith age group present in the inventory at the start of the first aging cycle, given by $I_i^{(1)}$, will lose $\hat{f}_i I_i^{(1)}$ engines while aging the first 20 hours. The number of survivors in the ith age interval are now 20 hours older; they are given by



(a) Major Overhaul Removals



(b) Hospital Removals

FIG. 6. Forecasting Factors for Major Overhaul and Hospital Removals by Months.

$$I_{i+1}^{(2)} = I_i^{(1)} - \hat{f}_i I_i^{(1)}, \qquad i = 1, 2, \cdots, 59.$$

To obtain $I_1^{(2)}$, we must take into consideration the total number of removals during the first aging cycle plus new installed engines to be received during the second aging cycle, both of which will be assumed to start the next aging cycle in age interval $i = 1$. Thus,

$$I_1^{(2)} = \sum_{i=1}^{60} \hat{f}_i I_i^{(1)} + \left[\begin{array}{l}\text{Installed Engines to be Received on New Aircraft During Aging Cycle } 2\end{array}\right]. \quad \text{Eq. 5.}$$

During 1957 there were a total of 4012 hours per installed engine schedule to be flown, or a total of $4012/20 = 200.6$ aging cycles. For phasing-in of the engines received on new aircraft, it is necessary to align calendar time with the aging cycle, as shown in Eq. 5. in order to determine the proper cycle for entry into the system. Also, in forecasting removals by calendar months, it is necessary to transform the forecasted flying time per installed engine, to aging cycles. For example, the January forecast was 341 hours per installed engine, or $341/20 = 17.05$ aging cycles. Thus,

$$\left[\begin{array}{l}\text{January Major Overhaul Removal Forecast}\end{array}\right] = \sum_{i=1}^{60} \hat{f}_i I_i^{(1)} + \sum_{i=1}^{60} \hat{f}_i I_i^{(2)} + \cdots + \sum_{i=1}^{60} \hat{f}_i I_i^{(17)} + 0.05 \sum_{i=1}^{60} \hat{f}_i I_i^{(18)}.$$

COMMERCIAL AIRLINE METHOD

The forecasting method currently used by some of the commercial airlines is based on a "Forecasting Factor," which is an estimate of the average number of flying hours per removal. These estimates are usually made up from the past six months of observed data. For example, the Forecasting Factor based on the data given in this study for the months $j = 28$ through $j = 34$, is as follows:

$$\left[\begin{array}{l}\text{Forecasting Factor For Major Overhauls}\end{array}\right] = \frac{\sum_{j=28}^{34} P_{\cdot j}}{\sum_{j=28}^{34} F_{\cdot j} + \sum_{j=28}^{34} T_j}$$

$$= [943 \text{ Flying Hours Per Removal}]. \quad \text{Eq. 6.}$$

In this expression, T_j is the total number of time removals occurring in the jth month. These Forecasting Factors are given individually by months in Figure 6 for major overhaul and hospital removals. The large values of the major overhaul removal forecasting factors in months 1, 2, and 11 were caused by the large quantities of new aircraft received in these months. Also the relatively large variation in the hospital removal forecasting factors is due to the fact that there were fewer hospital maintenance removals observed in this study, compared to major overhaul removals and secondly, all hospital removals occur at random as opposed to the non-random maximum time removals which account for about half of the total major overhaul removal quantities.

The forecast of removals is made by dividing the proposed hours to be flown for the month in question by the Forecasting Factor. This forecasting method differs from the inventory aging method in that no consideration is given here to the age of the installed inventory and the corresponding relationship between age and the probability of occurrence of a failure removal.

COMPARISON OF THE FORECASTING METHODS FOR MAJOR OVERHAULS

The period January 1957 through August 1957 was used for comparing the above forecasting procedures for major overhaul removals. The actual removals as well as the forecasts for these two procedures are given in Table 5.

TABLE 5

Major Overhaul Removals Observed and Forecasted for the Period January 1957 Through August 1957

Forecast Month	Average* Number of Installed Engines During the Month	Observed Major Overhaul Removals			Airline Forecast of Total Major Overhaul Removals**	Inventory Aging Forecast of Total Major Overhaul Removals
		Failure	Time	Total		
January	44	6	5	11	15.9	12.2
February	44	7	4	11	14.4	12.3
March	44	6	5	11	15.9	15.8
April	44	3	13	16	15.4	15.7
May	44	6	5	11	15.9	14.5
June	45	7	4	11	16.2	16.0
July	48	7	8	15	17.3	17.2
August	54	6	10	16	19.5	17.4

* Rounded off to the nearest whole number.
** The "forecasting factor" used here was 943 flying hours per removal.

The standard deviations of the forecasting errors for each method, along with an estimate of the lower bound thereon, are as follows:

Method	*Standard Deviation in Removals Per Month*
Airline Forecast	4.3
Inventory Aging Forecast	3.2
(Lower Bound)	2.5

The lower bound standard deviation is based on the hypothesis that only the random failure removals (total removals minus the maximum time removals) contribute to the forecasting errors, and these removal quantities are distributed according to the binomial distribution. Thus, the lower bound standard deviation is approximately equal to

$$\sqrt{\bar{n}\bar{p}(1-\bar{p})},$$

where $\bar{n}$ is the average number of installed engines during the forecasting period and $\bar{p}$ is an estimate of the probability of an engine undergoing a failure removal during one month of flying.

The sample size involved in this comparison study—namely, 8 months—was too small for any of the above differences to be judged statistically significant. However, it is felt that the standard deviations are indicative of the true precision of these forecasting procedures.

CONCLUSIONS FOR PART II

A comparison of the Airline and Inventory Aging Methods of forecasting major overhaul removals indicates that the latter is more precise, and further, that it is fairly close to the "ultimate" method. The Inventory Aging Method has even greater potential where long range forecasts are desired because of its consideration of the age of the engines and the "phasing-in" of new aircraft into the system. This factor can be of considerably greater importance for other types of aircraft engines if the failure rate curves show more curvature than was found in this study of the R-3350 type engine. The advantages of the Inventory Aging Method are offset to some extent by the fact that it requires the use of a computer of the IBM 650 size. The computations can be reduced somewhat over those performed in this study, however, by increasing the width of the aging interval from 20 hours to 50 or possibly 100 hours.

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(2) MILLER, M. D., *Elements of Graduation*, Actuarial Society of America, Chicago, Illinois, 1947, Chapter 4, pages 30 and 32.

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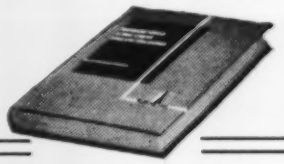

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Cross Charting Technique as a Basis for Plant Layout

by **MARSHALL SCHNEIDER**

Administrative Assistant to the President, Charles D. Barnes Company, Boston

SEVERAL articles have been written relative to the cross charting or travel charting techniques. Most of these articles have dealt with theoretical or purely analytical techniques and do not necessarily present a practical approach that is either economical or simple to apply.

This report has been prepared to show the steps that were taken in the development and application of a cross chart used as a basis for the development of the Machining Division for the Walworth Company's new Braintree, Massachusetts Plant. In addition to this, all the known various approaches for preparing the cross chart are explained.

Basically, manufacturing falls into three categories: product line or continuous production, process line or job shop, mixed product-process line or production-job shop.

For the continuous production and the job shop type of arrangements, we have had, for many years, well developed and tested tools to use for the analysis and development of the layouts: flow process charts and diagrams. However, when it comes to the analysis of the production in a plant that has high volume and job-shop production intermixed, the problems of analysis are very complex and the tools available to make this analysis have been poor. This has led many concerns to use the process-type layout which, in most instances, is not the best arrangement to afford the least amount of materials handling and the highest degree of overall efficiency for the flow of materials between operations. The cross chart technique is the most up-to-date and soundest tool to use for making this type of analysis.

The basic concept of the cross chart is somewhat analogous to the law of physics that "energy can neither be created nor destroyed"! *Energy In* must equal *Energy Out*. The industrial "Energy In" is measured in terms of labor (manhours) and mechanical power. The object of industry is to operate at as low an input of these factors as possible. Therefore, the object of a good, sound layout is one where the arrangement of the plant is such that the amount of labor and power expended to move materials is at a minimum. The only factor in the industrial "Energy In equals Energy Out" equation that offers any opportunity for reduction, and which is the controlling factor for the entire equation, is the distance that the material has to be transported between operations, inspections and storages. The closer this factor can be made to approach zero, the less input will be required, hence the lower the cost of material movement between operations.

In the initial stages of developing the cross chart, two types of data are necessary. One is the sequence of operations required to produce each part, and the other is the total volume of each of these parts to be produced in a given period. The first item we will call the Flow Sequence Data and the second item will be known as the Production Forecast. The Flow Sequence Data may be obtained from methods sheets, process charts, operation sheets or similar records. The volume indicated on the Production Forecast can be in terms of pieces, weight, number of unit loads or any other common volume denominator that will show the true volume handled.

Before these data are accumulated, one basic decision must be made—what degree of accuracy will be required in the end result? If the accuracy required is 100%, then it will be necessary to tabulate each and every item that will go through the area under analysis. On the other hand, should normal statistical accuracy be adequate, then the number of products to be analyzed will be determined and selected by the application of the statistical sampling formulas. It is the second approach which is the most practical for most manufacturing concerns to use.

Here, again, there are two ways to select the sample. One is through the strict application of the sampling formulas and the use of random number tables, and the other is by selecting the high-volume products which are typical of each different type of series of flow sequences. This approach works very well because the sample, if large enough, would represent a very large proportion of the total production with the least number of parts.

There are three methods by which these data can be accumulated and posted to the cross chart.

METHOD 1 FOR SMALL PROJECTS

A. Tabulate the flow sequences on a sheet of paper as in Figure 1.

To each different flow sequence assign a flow sequence number. If the exact same flow sequence is used for more than one item, the sequence number will be repeated for each identical item.

B. Prepare a production forecast chart for all the items under study similar to Figure 2.

C. The Data accumulated on the flow sequence chart and the production forecast chart are now merged on a summary sheet as in Figure 3.

D. The cross chart is now made ready for posting by listing all the Work Centers appearing on the summary sheet. In addition to these, a "From" column is headed "Shipping", Figure 4.

Product	Operation (Work Center)			Flow Seq. No.	Product	Operation (Work Center)			Flow Seq. No.
	1	2	3			1	2	3	
A	4	7	3	1	F	2	6		5
B	2	6	3	2	G	4	7	3	1
C	5	1	3	3	H	4	6		6
D	4	1		4	I	5	1		7
E	2	6	3	2					

FIG. 1. Flow Sequence Sheet.

E. Scan Summary Sheet for Flow Sequence number 1 and post the Volume going into the primary Work Center in the respective block on the Cross Chart, i.e. if the primary Work Center in flow sequence number 1 is Work Center 7, then in the block under "From Receiving" and along side "To Work Center 7," post the volume indicated on the summary sheet. Be sure to scan the summary sheet for any other flow sequence number 1's and add their Volumes before making this posting.

F. Next, post where this material goes from Work Center 7. Assume that the material from Work Center 7 goes to Work Center 5. Post the total volume for all the flow sequence number 1's in the block under "From Work Center 7" and along side "To Work Center 5."

G. This is continued through all the Work Centers in each of the Flow Sequences with the addition of posting the last Work Center as "From (whatever the last work center number is)"—"To Shipping."

Simultaneously with the posting of the Volume to the Cross Chart, the number of different items going through each "From-To" combination is also posted.

METHOD 2 FOR MEDIUM SIZE PROJECTS

A. A card is set up for each part to be analyzed, Figure 5.

B. The flow sequence data and the volume for each part are posted on the card, Figure 6.

C. Sort the cards so that the Work Centers performing the first operation are arranged in numerical order and all cards containing the same primary Work Center are together.

D. Sort each group of cards containing the same primary Work Centers so that the second Work Centers and subsequent Work Centers are in order.

E. This last sorting step should bring all cards with identical flow patterns together. The duplicates are to be consolidated on one card. This one card takes the place of the duplicates in the deck.

This card should show the flow pattern sequence, the total of all the volumes and the number of parts represented. In adition to this, the parts identification could be posted on the card for reference purposes, but this is done as a convenience rather than a necessity, as you can always go back quite easily to the duplicate cards to find out what parts go through the flow pattern. At this point the cards are synonymous to the summary sheet used in Method 1 and are ready to be posted to the cross chart.

F. Take all the cards with the same primary Work Center of the lowest number and total the volume going into it. Post this total in the block on the Cross Chart under "From Receiving" and along side "To Work Center." Do the same for the next primary Work Center and all subsequent primary Work Centers. This would complete the posting of all material that would be coming into the area "From Receiving."

G. Reshuffle the cards so that all cards that indicate an operation performed at the Work Center with the lowest number are together (for this example call it Work Center 1), and so that the next immediate work centers are arranged in numerical sequence:

From Work Center 1 to Work Center 1
From Work Center 1 to Work Center 2
From Work Center 1 to Work Center 3
From Work Center 1 to Work Center 4
Etc.

The Volume shown on all the cards with "From Work Center 1 to Work Center 1" are then totaled and the total is posted to the Cross Chart in the proper block. The cards with "Work Center 1 to Work Center 2" are totaled next and posted to the Cross Chart. The shuffling and reshuffling are continued until all the Work Center combinations are posted.

Finally shuffle all the cards so that the last Work Cen-

Product	Volume	Product	Volume
A	4000	F	5000
B	1000	G	2000
C	3000	H	7000
D	3000	I	1000
E	1000		

FIG. 2. Production Forecast.

Flow Seq. No.	No. of items / Work Ctr	1	2	3	4	5	6	7
1	2			4000 2000 ⑤	4000 2000 ①			4000 2000 ②
2	2		1000 1000 ①	1000 1000 ③			1000 1000 ②	
3	1	3000 ②		3000 ③		3000 ①		
4	1	3000 ②			3000 ①			
5	1		5000 ①				5000 ②	
6	1				7000 ①		7000 ②	
7	1	1000 ②				1000 ①		

FIG. 3. Summary Sheet.

ters on the cards are in numerical order and post these in the "From Work Center-To Shipping." This completes the posting to the Cross Chart and it is ready for totaling and analyzing.

METHOD 3 FOR LARGE SCALE PROJECTS

For this method the data are set up on punch cards which are collated and printed by means of data processing equipment. This method is readily adaptable to punch cards, punched tape or magnetic tape. Whichever process is used, the method is basically the same.

The description that follows is for the preparation of the cross chart through the use of IBM punch cards.

A. From the Flow Sequence source data and the Production Forecast, a card is punched for each Work Center combination for each part under analysis. The data punched on the card are:

1. The part's identification
2. The "From Work Center"
3. The "To Work Center"
4. The Volume

Cards must also be punched to reflect the receiving of the material at the primary Work Center and the shipping of the material from the final Work Center.

B. The cards are next run through the interpreter where the punches are translated into printing on each card.

C. The cards are sorted by Work Centers and grouped in ascending order.

D. These are now put through the collator to be separated into sub-groups with identical Work Center combinations and into major groups of each "From Work Center." Sub-totaling cards are inserted between each sub-group and a totaling card is inserted after each major group.

		From Work Center								Total to
		Rec.	1	2	3	4	5	6	7	
To Work Center	1					1 3000	2 4000			3 7000
	2	3 7000								3 7000
	3		1 3000					2 2000	2 6000	5 11000
	4	4 16000								4 16000
	5	2 4000								2 4000
	6			3 7000		1 7000				4 14000
	7					2 6000				2 6000
	Ship		2 4000		5 11000			2 12000		9 27000
Total from		9 27000	3 7000	3 7000	5 11000	4 16000	2 4000	4 14000	2 6000	

FIG. 4. Cross Chart.

E. The cards are run through the printer which will print the part identification, the "From Work Center," the "To Work Center" and the Volume. After each group of identical work center combinations the sub-total for that group is printed and at the end of each complete group of "From Work Centers" the total is printed.

F. The posting to the Cross Chart is made directly from this sheet by copying, in the proper "From-To" blocks, the Volume and number of parts going through that combination. The totals are posted in the "Total From" column and after the chart is completely posted these totals are transferred to the "Total To" row for each respective work center. The Cross Chart is now ready for analysis.

ANALYSIS OF CROSS CHART

The example shown here is a simplified version of the Cross Chart in order to make the explanation of the analysis technique easy. The analytical steps taken and the consideration given to the combinations in this example are identical to those used for a full scale cross chart analysis.

The first Work Centers that are analyzed are those performing the primary or first operations. These Work Centers are those that would be placed closest to the receiving area.

By scanning the "From Receiving" column on the Cross Chart, Figure 4, it is noted that Work Center 4 processes the larger volume of work as well as the largest variety of items. This then means that Work Center 4 should be placed closest to the receiving area.

Work Center 2 has the second largest volume and is placed in the next relative position from the receiving area.

Similarly, Work Center 5 has the least material coming to it from the receiving area as related to the other primary work centers and would therefore be placed in the farthest location. This completes the analysis of the primary work centers and places them in the proper relation to the receiving area in accordance with the volume coming to them from the receiving area.

Part#			Volume	
Flow Sequence#				
Operation	1	2	3	4
Work Center				
Operation	5	6	7	8
Work Center				

Fig. 5. Flow Sequence Data Card.

Part# 7326-5			Volume 90362	
Flow Sequence #7				
Operation	1	2	3	4
Work Center	6	9	3	8
Operation	5	6	7	8
Work Center	17			

Fig. 6. Posted Data Card.

The next Work Centers to analyze are those performing secondary operations. The place to start is with the primary Work Center handling the largest volume from the receiving area. This is Work Center 4.

Inspection of the Cross Chart shows that of the 16,000 products processed, 7,000 go to Work Center 6, 6,000 go to Work Center 7 and 3,000 go to Work Center 3. At a first glance it would appear that Work Center 6 should be placed closest to Work Center 4. However, closer inspection of Work Center 6 and 7 reveals that while Work Center 6 receives the largest output of Work Center 4, it also receives an equal volume from Work Center 2. In addition to this, it handles a larger variety of products from Work Center 2 than it does from 4. This indicates that Work Center 6 should be favored closer to Work Center 2, than 4. To further verify this decision, it should be noted that all the material coming to Work Center 7 came to it directly from Work Center 4 and a larger variety of items pass between 4 and 7 than between 4 and 6.

This type of condition should be noted for further study at the conclusion of the analysis. The reason for this is that when a work center receives or disburses all its material from or to another work center, it is indicative of the possibility of linking these work centers together for continuous, straight-line or conveyorized production.

It is further found that Work Center 2 passes all its output to Work Center 6, and it can now be said, that the proper relationship of Work Centers 6 and 7 is to place Work Center 6 closer to 2 than to 4, and Work Center 7 closer to 4 than to Work Center 6.

Returning now to Work Center 4, it is found that the

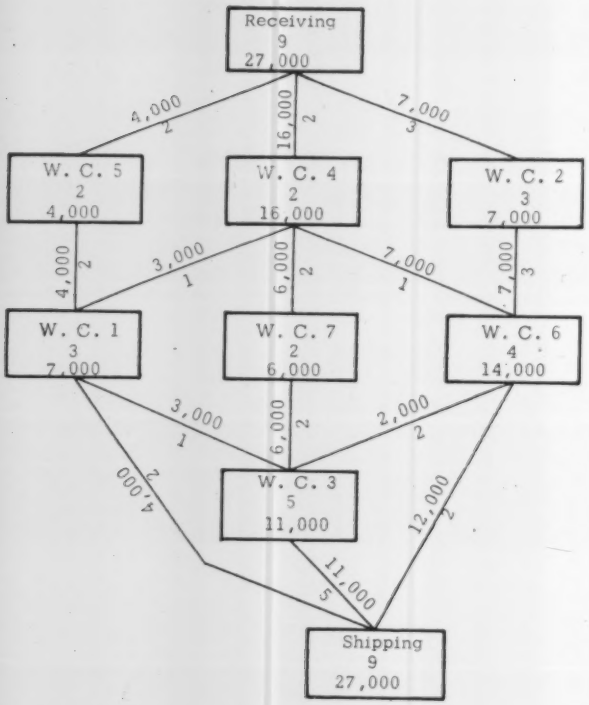

FIG. 7. Block Diagram.

balance of the material from this Work Center goes to Work Center 1. Further investigation of Work Center 1 shows that it receives not only a larger volume from Work Center 5, but also the entire output from 5. Therefore, Work Center 1 should be placed in a position relative to 4 but favoring Work Center 5.

At this point, Work Centers 4, 2, 5, 7, 6 and 1 have been analyzed and their relative positions to one another have been established. This leaves Work Center 3 to be analyzed.

Investigation of the Cross Chart shows that Work Center 3 receives not only its greatest volume from Work Center 7 but it also receives the total output of this Work Center. There is no question then that it is to be placed nearer to Work Center 7 than to 6 or 1, from which it also receives material.

At this stage of the analysis, all the Work Centers have been set in the proper relation to each other.

The final stage of the Cross Chart Analysis calls for placing the shipping point in its proper relative position.

Investigation of the Work Centers delivering material to the shipping point shows that Work Centers 3 and 6 deliver the largest Volume. This is an instance where it is a bit questionable as to which one of these two Work Centers the shipping point should be closer related. The reason for raising this question is that even though Work Center 6 processes a larger volume going to the shipping point than Work Center 3, it is handling a smaller variety of items. The only way to definitely ascertain its proper relative position is to further investigate the physical nature of the products being processed through these Work Centers. However, if the differences between the 2 volumes are not too large or are deemed inconsequential in either magnitude or difference, it becomes immaterial where it is placed, and the general rule would be to place it nearer the Work Center delivering the larger volume, but with a possible favoring towards the other Work Center.

This fixes the relative position of the shipping point nearest to Work Center 6 with a possible favoring towards Work Center 3. Work Center 1 does not carry too much weight in deciding toward which Work Center the shipping point is to be placed nearer, except that it does dictate that there should be a slight skewing of the shipping point in the relative direction of Work Center 1.

The block diagram of the relative position of all the Work Centers is now complete and it should look like Figure 7. It now remains to substitute the actual items of equipment for the blocks and to make adjustments to the layout of the equipment as dictated by several factors. Some of these factors are:

1. The physical size of the Work Center.
2. The number of work stations in each Work Center.
3. The relative locations of similar types of equipment or similar performances of operations.
4. Physical restrictions, limitations or interferences within the area or building where the layout is being made.

These represent some of the major reasons why equipment or work stations sometimes are not placed where they should be. There are many lesser factors which influence the proper locating of work stations, such as the location of power and utilities, natural light sources, exhaust outlets, etc. Regardless of what effects these factors have, the closer to the block relation diagram that the layout can be maintained, the more proper will be the relative positions of the Work Centers. Before a Work Center is moved to a position, out of relation to the block diagram, reference should be made to the Cross Chart to determine towards which other Work Center it could be moved, so as to render the least loss of relationship with all the Work Centers not only delivering material but also receiving material from the altered Work Center.

CONCLUSION

It is to be noted that the distance between Work Centers has not been considered nor has mathematics been applied to the application of this technique. There are two items which must be remembered:

1. That the ultimate object of a layout project is to place Work Centers so that there will be the least amount of total travel between them.
2. That much layout work is being performed by people who do not have the training nor the background to understand and apply higher mathematics.

In the opening paragraphs, I said that the closer to zero that the summation of the distances that the total product must travel between Work Centers, the lower will be the input of energy and cost. When the relationship is correct, the summation of the distances and volumes between related areas or Work Centers will be at the lowest possible value, hence the cost will be lowest.

The purist may take exception to this approach, but to be practical it must be realized that when arranging equipment or departments we are placing them in chronological order with regard to the amount of work that passes through them. The larger the volumes passing between them, the more closely they should be related. We are not interested in the distance between the work stations, because these are controlled by physical characteristics. So long as we have the proper relationship, regardless of the magnitudes, the distances will be as close as possible.

All the work, except for the final analysis of the chart, can be done by clerks. This is a technique which fulfills the requirements of being simple and straight-forward, and provides the required information with indisputable accuracy.

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Measuring Manufacturing Performance

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Manufacturing Manager, Unitary Equipment Operation, Carrier Air Conditioning Company

CERTAINLY, all Industrial Engineers have felt the pressure from management for more efficient operations in order to withstand the increasingly difficult cost-price squeeze. This comes during a business year which gives every indication of being one of the most competitive in the past decade, with profits correspondingly harder to obtain. This is not to say that sales will slump, but rather that the same level of sales will not bring as high profits as formerly. In such an atmosphere, the management that merely maintains the *status quo* will probably suffer a loss in market position and profits. Many manufacturers entered into new lines of business in the middle 1950's, as diversification became the keyword of industry, and this coming period will be their first severe test. Many of the nation's executives have never been faced with a really severe competitive fight, since they have been a part of our expanding economy only since World War II.

The coming year will see a battle of competing products and managements which only those that plan intelligently will survive. This applies as much to the industrial giants as to the small, local businesses. Most companies recognized the coming cost-price squeeze early in 1957 and took steps then to meet it. This means that by now all the easy savings have been found and wrung out of their operations. Future cost reductions and improved production efficiencies, now more important than ever, will be much more difficult to attain. As men primarily concerned with this task, you will discover these savings more easily if you use intelligently conceived criteria to point up your particular problems.

We are interested in the manufacturing portion of a company and how to quickly and accurately keep our finger on it pulse. Of the four vital areas of industrial control—*budgets, sales, production* and *inventory*—manufacturing is directly involved with three. For this reason, and perhaps also because profits and sales are related to production costs and plant activity, top management turns to the manufacturing group as the first line of defense against the cost-price squeeze. When operations are being curtailed, as has been true generally throughout industry this past half year, costs never seem to be cut back as quickly and as much as they should be. In this situation what we all need is a small amount of second sight, but, this, of course, is impossible. The next best thing is indicators pointing the way to potential areas of cost reductions and unbalanced operations.

CRITERIA

There is nothing magical or revolutionary about the criteria that we use to keep track of operations at Carrier. Looking in production handbooks, you will find page on page of neatly printed formulae designed to measure almost every conceivable aspect of manufacturing operations, and the controls we use are among them. However, blind use of these formulae will probably lead to trouble. As you well know, statistics can be made to prove almost anything, depending on how the analysis is made. There is still no replacement for judgment based on a sound background of experience. Properly used, there is a place and use for industrial measurements if they are tailored to the needs of the situation and meet several critical tests. To be effective, I believe they should be as follows:

1. Based on readily available, current data.
2. Used to measure key areas.
3. Presented in easy to understand fashion.
4. Evaluated in the light of the past history of the company and the industry.
5. Placed in the hands of key supervision for action.

High speed data handling devices have made it possible to obtain current reports on critical operations. Probably the words "current" and "critical" deserve special emphasis here, for they are the heart of any really effective control system. The manufacturing group is directly responsible for making proper use of the new techniques for data handling. Most accounting groups are more than happy to give any information desired, but it is up to us to tell them what is needed, when, and in what form. Constant attention must be given to explaining our current needs or we soon find our time is being consumed in trying to cull information from poorly organized reports whose formats were meant to serve purposes long since outdated. A perfect example of this arose in our operations not long ago. At budget time we suddenly realized that we had almost 25% of all our expenses lumped in one account called "Production Control" and were obtaining no real control at all. When the budgeting system was started, Production Control expenses were small enough to be carried in one account. But, as our operations grew, no one stopped to analyze the system to see if it still was applicable. We now have corrected this situation by breaking the budget down into several smaller, more easily managed accounts.

Some measurements are universal in their application and evaluation, but most should be considered in the

light of the type of industry and the past history of the Company. Lastly, these guideposts should not be the exclusive property of the manager. The information should be made available to all concerned so that they know their goals. By delegating responsibility and authority properly, along with giving a clear understanding of what you expect in the way of results, your own job will become much easier.

In listing the manufacturing controls, we find they generally fall into three well known categories: *material, labor and burden.* Product cost is composed of these three items, and when the sales manager wants to examine the sales price of a product in order to stay competitive, the cost reduction needed to maintain profits lies in these items. Almost universally, material represents the largest single consumer of manufacturing dollars. It is responsible for roughly 70% of product cost. A commonly accepted rule of thumb for the breakdown of product cost is as follows:

Material	70%	= Product Cost
Direct Labor	10%	
Burden	20%	

MATERIAL

Since material represents such a substantial portion of manufacturing costs, I should like to discuss measures of performance in this area first. Too high or too low inventories, inadequate accounting for materials, excessively expensive materials, and, conversely, cheap materials are all problems that must be faced and solved by the manufacturing groups. Cheap materials usually point the finger to themselves with a rash of loud and costly consumer complaints. Insufficient inventories are also painfully brought to management's attention by expensive production line shutdowns. But, what about the other problems that may be equally expensive and yet are not as self-evident?

Excessive inventories make themselves apparent in several ways. First of all, I believe in the simple yet effective policy of getting through the shop daily. A trip through the plant will usually tell one whether or not excess material is stacked up on the production floor. At the same time the sight of skids of partially finished material with old move tickets indicates that a bottleneck operation or poor scheduling is holding up production. These visual observations, coupled with a monthly check on the inventory turnover rate, will give a fairly accurate picture of the status of inventory levels. Inventory turnover, of course, is the ratio of total material used to the average value of inventory for a specific period—usually a year.

Naturally, every inventory has its own acceptable turnover rate based on such items as production methods, procurement and in-plant lead times, and the performance of any specific organization should be measured against the proper industrial standard. The following illustration shows the amount of money that can be saved here.

If a company which consumes $1,000,000 worth of material a year can improve its turnover ratio from four to five, the average capital investment in inventories is reduced from $250,000 to $200,000. This releases $50,000 of capital or 20% of the average inventory value for other uses. Since the carrying charge for inventory due to handling, distribution, facility charges, interest, depreciation, and obsolescence is estimated at 15% per year of the value of the inventory, an additional $7,500—15% of $50,000—is saved yearly. The actual dollar value of inventory in this example is probably below that of most companies. The importance of the illustration is in the percentage of savings: 20% of capital investment and 15% of the reduction of average inventory value is saved when the turnover rate is increased from 4 to 5. I am sure that these figures point out the importance of watching the turnover rate closely with the idea of improving it.

INVENTORY CONTROL SYSTEMS

There are many systems of inventory control; we have adopted the *ABC* System. Inventories break themselves down into three groups based on inventory quantities and cost. These three groups are called *A, B* and *C*, hence the name for the system.

Let us take a look at the relative values of these three groups:

The *A* group, representing approximately 20% of the number of items, equals about 80% of the inventory dollar value.

The *B* group, representing 25% of the items, equals 15% of the inventory dollar value.

The *C* group, representing approximately 55% of the items, equals 5% of the inventory dollar value.

For proper control, the high priced, low volume *A* items are watched weekly or even daily by those responsible for inventories. This tight control of relatively few items insures that 80% of inventory investment is kept at a closely watched minimum. An example will help show the effectiveness of this method: Assume an average inventory of $5,000,000 composed of 16,000 items and controlled by eight material control workers. Then the *A* items represent $4,000,000 of the inventory, but only 3,200 of the parts. This means that each one of the eight workers must watch only 400 parts daily, or weekly, of his assigned 2,000 parts in order to control the majority of the investment.

Large volume, low cost *C* items such as nuts and bolts are controlled on a simple inexpensive clerical basis, using specified maximum and minimum inventory levels that need only periodic attention, for large quantities of these parts can be kept on hand at a small cost. The *B* group falls in between the other two and should be controlled accordingly.

The objectives of this system are to concentrate attention on the valuable repetitive items of inventory and to develop inventory policies and procedures that embody the best controls for each group consistent with their value. In plain language this means to invest the time of material control personnel where it will do the most good—on the expensive items.

The benefits of such a system are many:

1. Reduced inventory value.
2. Increased turnover rate.
3. Reduced setup and run costs for the *B* and *C* items that are manufactured.
4. Reduced material handling costs.
5. Highlighted benefits of parts standardization and better guides for material cost reduction efforts.
6. Smoother operations—full attention is concentrated on *A* items while *B* and *C* are run only periodically.

The *ABC* system will help to accomplish many inventory objectives by focusing attention in the proper place. At the same time it provides data ready-made to act as measurements. As an example, the number of items in the various categories measures the extent of parts standardization. We recently reduced the number of fastenings used on one line of products by a third, simplifying our inventory problem at the same time. These results are easily measured each time a tabulation of *A*, *B* and *C* parts is made.

The amount of scrap a plant generates is another important measure of the efficient use of materials. Recent reports show that about one-fifth of all the iron, steel, copper and aluminum that enter the average metal working plant ends as scrap. If you use a lot of copper, as we do at Carrier, this scrap can become expensive. An excessively high scrap rate indicates poor materials or careless operations and in either case calls for immediate action.

DIRECT LABOR

Now, let us turn our attention to the second area of product cost—direct labor. Of the three factors—material, labor and burden, direct labor costs, although only 10% of product costs, receive probably the closest scrutiny throughout industry. An editorial in the December, 1957 issue of *Appliance Manufacturer* entitled "The Real Advantage," is worth repeating:

> Most top manufacturing executives in highly competitive industries have already learned that it takes all the ingenuity and resourcefulness they possess merely to keep up with their competitors.
>
> Since sustained competitive advantage is generally not to be had today by way of possessing things and procedures, where does the aggressive manufacturer look for it. In superior job performance.
>
> The high road to sustained competitive advantage today lies in job performance by all employees, day in and day out, that is consistently superior to that of the competition.
>
> Superior job importance all along the line is vital.

Although this quotation makes no distinction between direct and indirect labor, what it says applies particularly to the former because of its definition. For cost accounting and control purposes, the general rule is: Direct labor is that labor spent in actual production of the product. Indirect labor represents auxiliary work done in connection with product manufacture. It is labor not engaged in changing the form of the product, but which performs essential services. As such it is generally considered a part of burden.

The importance that industry places on a superior job performance by direct labor is readily apparent when we take time to consider the lengths that management goes to measure this performance. There is hardly a company today that does not employ some type of incentive wage system as a means of obtaining peak performance from its direct labor workers. The need for administering such complicated wage systems has opened the new field of timestudy and work measurement. Management is willing to bear the expense of this added overhead because it is one of the few pure measurements of job performance.

It is extremely important that supervision be able to measure the efficiency of the direct labor. As far as production is concerned, it is the catalytic quantiy that can make the factory hum or squeak, and as such must have both the proper *quantity* and *quality*.

Labor variances measured from standard costs are the criteria for controlling direct labor. Under such a system it is equally important that deviations under standard be watched as well as those over standard. Excessive favorable deviations may indicate loose standards or poor job methods which the employee has secretly improved on. Unfavorable deviations may be due to tight standards, excessive schedule changes, new products, poor work pace, machine breakdowns, material shortages, or numerous other causes.

In our system we report weekly, by department, the total standard cost of labor, the actual cost, and the total deviation between the two. The total deviation is broken down into first run, regular run, new man training, lack of material, lack of crane service, machine breakdown and miscellaneous categories.

"First run" applies to labor expended on new products or jobs run for the first time on which the employee is not working under a timestudy rate. Regular run shows the deviation on rated jobs and measures the true efficiency of the workers. My experience has been that labor standards can be established accurately within plus or minus 5%. Labor deviations in excess of this, both favorable and unfavorable, should be investigated.

Although our system deviates somewhat from the conventional, it suits our needs. It serves to point out that standard costing of labor is a flexible thing that must be tailored to each situation for the most effective results.

In the area of direct labor, as in materials, I value the daily trip through the shop which permits a first hand

evaluation of the operator's pace. This information, together with weekly labor reports, gives me an accurate picture of the labor situation.

Up to now, we have been discussing labor quantity. Now, let's turn to its quality. All companies take considerable pride in their product and in selling a quality item to their customers. It is an old manufacturing axiom that this quality must be built into the product, because it cannot be inspected into it. One of the basic ingredients to built-in-quality is the first rate, conscientious production line employee who takes pride in his job.

Certain controls are necessary to insure that high quality is being used to build high quality products. This control can be obtained simply by watching the process rejection rate. Every process has a certain amount of inevitable rejects. This normal rejection rate is computed from historical data and becomes an index to the process quality. When rejects climb above this level, it becomes management's job to analyze the situation. Carelessness of job performance, bad vendor materials, inadequate methods and many other possibilities should be examined.

MANUFACTURING EXPENSE

The third and final area of product cost that must be controlled is that of burden or, as it is sometimes called, manufacturing expense. It includes such items as indirect labor, depreciation, rent, supplies, salaries, maintenance, water, training, heat, and light. All of these various expenses represent about 20% of product cost, but they can grow to be much more if not properly controlled. Because they cannot be related directly to production levels, burden expenses easily get out of hand, unless proper measurements are used to keep them in balance with direct labor activity.

Let's take a look at some of these expenses. Indirect labor represents a substantial portion of the total burden —about 20%. By adjusting its level to correspond with direct labor activity, a large part of overhead is controlled. We strive for an indirect to direct labor ratio of one to two before we consider our operations to be in balance. This can be broken down to include the ratio of production control employees to direct labor. We should have five indirect employees for every ten direct, with only two of those five in production control. The other three are divided about equally between inspection, maintenance and shipping and receiving.

A relationship also exists between the total number of hourly and salaried employees. This ratio should be about two to one. Salaries like indirect labor represent almost 20% of the overhead. Thus, with these two ratios, it is possible to keep employment at a level justifiable by current production activity and at the same time control about 40% of the total burden.

Budgets are the other important means of controlling burden levels. There are two phases involved here—the planning phase and then the control phase. Expense budgets are normally planned according to an expected production level. Our manufacturing expense budgets are based on a direct labor estimate for the coming year, which is in turn derived from a production forecast. Expenses are divided into fixed and variable groups. The amount of the variable portion of the budget is then adjusted each month, this being based on the difference between the actual direct labor and the forecast. This provides the means for measuring actual performance geared directly to our plant activity level.

The planning phase of budgeting is the foundation for the controlling phase. Unless realistic budgets are established, the controlling phase becomes very difficult, if not impossible, to carry out. The best guides here are historical data plus the known improvement factors that are possible. When it comes time to use the budget as a control, those costs which are under budget are just as significant as those over. There is much to be learned from both figures, although those accounts in the black usually don't have the same urgency as the red ones do.

SUMMARY

Since we have discussed the three areas of manufacturing costs—material, labor, and burden, we might redefine manufacturing controls as those tools used by management to insure not just profitable but, rather, the most profitable mode of operation. They are much like the score board that tells a team whether it is ahead or behind its competitors and, if need be, how far it must go to catch up.

Over a long time, only a logical plan of attack will bring results in cost reduction efforts. By subdividing costs into the areas of material, labor, and burden and weighing their relative importance, we have established a firm foundation from which to meet the problem. Through the use of turnover rates, scrap percentages, the *ABC* inventory system, ratios between direct, indirect and salaried personnel, standard costs and budgets, *specific goals and controls for each cost area can be established.*

I am sure we all realize that these three costs cannot be analyzed as if they were completely separate from each other. To a certain extent all costs are interrelated and when one goes down quite often another will rise. It is our job to work toward the optimum situation which insures the very smallest overall cost.

I have attempted to show how we try to accomplish this at Carrier. Certainly, ours isn't the only or best way of control for every company to follow. For, what controls are used is determined primarily by the specific problems that face an organization. But, if I wanted to leave you with one idea that can be applied under any circumstances, it would be that material, labor, and burden are the key to the cost control picture when considered as interlocking expenses and controlled as such.

Planning for the Use of Overhead Monorail Non-Reversing Loop Type Conveyor Systems for Storage and Delivery

by **WILLIAM B. HELGESON***

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THIS article is the result of work done in the Home Laundry Department of the General Electric Company, Louisville, Kentucky. The original study was divided into two parts:

1. The development of a theory useful in the study of overhead conveyor systems linking a producing system with uncertain production with a using system with uncertain consumption, and subject to the severe mechanical limitations imposed by such a conveyor.
2. The development of practical planning techniques including a nomograph, to assist the conveyor systems planner in achieving a better solution to the conveyor system design problem than was possible with the "rule of thumb" techniques commonly in use.

The results of the first phase were reported by Kwo (1). The results of the second phase are reported here.

INTRODUCTION

Overhead conveyor systems are widely used in high volume industries to connect one or more producing systems within a factory with one or more using systems. These conveyor systems use the overhead air space to perform the transportation, and often the storage function.

Two basic types of overhead conveyor systems with dozens of minor modifications are in common use.

1. *Closed-Loop Systems*

Part carriers are permanently attached to a chain or rod conveyor that runs on an overhead monorail or channel. The chain usually runs continuously in one direction and the rail or channel traces a closed loop between points.

2. *The Open-Loop Systems*

Part carriers are suspended from a separate track or rail from that carrying the driving chain or rod conveyor. Carriers are capable of removal from or addition to the main line of the conveyor on command and transferred to or from secondary loops, stationary locations or storage. The chain usually runs continuously in one direction and traces a closed loop between points. These systems are often called "power and free" because of the ability to switch from the driven to the free condition on command.

The closed-loop systems are generally much simpler and lower in cost per unit length or per unit capacity than the open-loop systems, but they are not nearly so flexible. The low cost of the closed-loop systems has resulted in the economy minded applying them to situations where it is false economy, and in some cases to situations where it is impossible for the system to perform its desired function. The mechanical design of closed-loop systems is very well understood, but their operating characteristics as part of an integrated manufacturing system have not, until recently, been understood.

On the other hand, the flexibility of open-loop systems has resulted in their use where the proper application of closed-loop systems would have been far more economical. The operating characteristics of the open-loop systems are quite easy to predict, on theoretical grounds at least, lending an aura of confidence to their use. Their use is often the easiest way out of a problem, even though it may not be the economical way out.

USES OF CLOSED-LOOP SYSTEMS

Closed-loop overhead monorail systems are used for:

1. Delivery only: delivery side loaded at exactly the delivery rate, return side empty. (See Figure 1.)
2. Storage only: each carrier completely filled, the conveyor indexed away from the loading point one carrier at a time for storage and indexed back to the loading point for removal from storage.
3. Both storage *and* delivery under dynamic conditions: parts on both the delivery and the return side of the conveyor.

This presentation will discuss the specific case of the storage and delivery version of such conveyor systems as it is the most complex of the three. In fact, the other two are merely limiting conditions of the more general case of combined storage and delivery.

A storage and delivery conveyor has an apparent storage capacity of P part spaces. These part spaces may be made up of N carriers with Q parts-per-carrier capacity,

* Thanks are due to T. T. Kwo, S. J. Maroda, D. P. Birnie, and J. Reigle of the Home Laundry Department for their help in developing and proving out the methods discussed.

spaced S feet apart over the length, L, of the conveyor. The conveyor operates at a velocity, v, and has a revolution time, W, of L/v.

The use of the word *apparent* is deliberate because these systems rarely have anywhere near the effective storage capacity that is *apparently* available from the P part spaces on the conveyor. One of the deadliest intuitive traps one can fall into when planning such a conveyor system is to assume that P part spaces means a net effective storage capacity of P parts under dynamic operating conditions. In actual operation a substantial number of the part spaces are not readily accessible. To illustrate the point, let us examine a conveyor delivering and storing one part type. No storage is to be allowed at either the loading point (left end of the conveyor illustrated in Figure 1) or the unloading point (right side of the conveyor illustrated in Figure 1). The producing system supplies R_L parts per minute when the producing system is operating. The producing system operates on a planned schedule including planned shutdowns, and is subject to random interruptions of its production rate. The using system demands R_U parts per minute when the using system operates. It operates on a planned schedule including planned shutdowns not necessarily "in time" with the producing system, and is subject to random interruptions of its operation. The conveyor system itself is also subject to random interruptions due to mechanical breakdown that impose additional random interruptions on both the producing and the using systems.

The only way the producing system can operate effectively when it is planned to operate is for the conveyor to present it with at least R_L empty part spaces per minute at the loading point. At any time that the conveyor system presents less than R_L empty part spaces per minute at the loading point the producing system cannot function continuously and smoothly without interruption (assuming *no* storage at the loading point). If the relationship of system parameters is such that the number of parts uniformly distributed along the length of the conveyor is increased by some very small increment with each revolution, it is quite clear that interference with the producing system will occur exactly at the time that the uniformly distributed empty part spaces drops below R_L part spaces per minute. Thus in the limiting condition $W \cdot R_L$ part spaces are unavailable for effective storage. The effective storage capacity of the conveyor is then not P parts but P parts minus $W \cdot R_L$. $W \cdot R_L$ is called the loading point accessibility reserve. In actual practice the incremental additions to storage per revolution are relatively large, so the number of inaccessible part spaces may be less than this limiting value for a particular set of conditions. The simplest technique for determining the loading point accessibility reserve for a specific set of operating conditions is by the use of a simulation to be discussed later. In the early stages of planning a conveyor system it is safest to assume that the full limiting loading point accessibility reserve of $W \cdot R_L$ will be required.

By a similar logic one cannot deplete the inventory of parts on the conveyor below that which continuously supplies the unloading point with at least R_U parts per minute. Again in the limiting condition the number of unavailable parts is $W \cdot R_U$ parts. Again, when planning a system it is unsafe to allow less than this limiting number $W \cdot R_U$ of parts as an absolute minimum inventory of parts on the conveyor. This number $W \cdot R_U$ of unavailable parts is called the unloading point accessibility reserve.

It is of interest to note that the value of these two accessibility reserves is a function of the revolution time (or velocity), the smaller the revolution time (the higher the velocity), the smaller the reserves must be. For this reason most conveyor systems of this type are run intuitively at their maximum technological velocity. The maximum technological velocity may be determined by:

1. The maximum possible chain speed.
2. The minimum time required to place one part in a part space or remove one part from one part space whichever is the larger value.
3. Other technological limitations such as centrifugal force on parts tending to throw them from carriers at turns.

However, as will be shown later, the maximum technological velocity may not be a workable system velocity.

Another phenomenon occurs on conveyor systems of this type. In order that they function with *maximum* effectiveness, parts must be uniformly distributed along the length of the conveyor. This rarely occurs, so the storage capacity of the conveyor, as determined by subtracting the two accessibility reserves from the total number of part spaces available, must be reduced by some amount to allow for non-uniform distribution of parts on the conveyor. Such non-uniform distribution of parts may occur because of temporary interruptions of either a planned or unplanned nature in either the producing system or the using system. Examples might be 10 minute personal time breaks, or short duration failures of either producing or using system. No practical method of analytically determining this discontinuity reserve is discussed here.

This is essentially a queueing type of problem if one is willing to make certain assumptions about the probability distributions of the non-uniformities. In the absence of such an analytic method, it is desirable to have a simula-

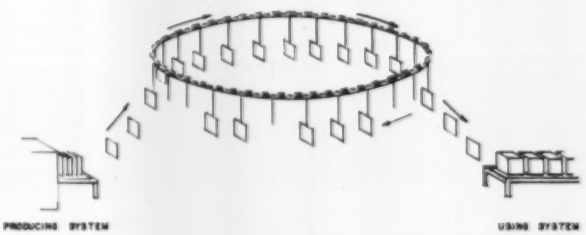

FIG. 1

tor of the conveyor system available to test the proposed conveyor system design over a wide range of system parameters. Such a simulator could then be used to quickly determine workable conveyor system velocities for specific proposed changes in production schedules after the final conveyor system is in place. If the simulation is to be done manually, it will be most convenient to subdivide the conveyor into time blocks of about the same time duration as the shortest planned interruption, and explore the cumulative buildup or depletion of parts on each section over time, ignoring random disturbances. If, however, a digital computer is available a more sophisticated simulator can be built to permit testing the proposed system over a wide range of schedules down to the ideal increment of one carrier, as well as to permit study of the effect of random interruptions by the use of Monte-Carlo techniques. The effect of this uneven distribution of parts reduces the effective storage capacity of the conveyor system and this must be taken into account in planning the system.

What is left, if anything, after the two accessibility reserves and the discontinuity reserves have been taken into account is the effective storage capacity of the conveyor. This is a system with a fixed storage capacity and a word of warning here is appropriate. Usually in planning the storage capacity requirement between any two manufacturing systems, account is taken of a minimum inventory point safety reserve to permit the using system to run for some predetermined time after the producing system shuts down due to an unplanned condition that occurs at the minimum inventory point. Many techniques are available for determining this minimum inventory point safety reserve, most of which assume an unlimited storage capacity and thus ignore the inverse condition, unplanned shutdown of the using system at the maximum inventory point. With storage systems of fixed capacity such as a conveyor system, allowance must be made for both the minimum inventory point safety reserve and a maximum inventory point safety reserve. What is left after all this, is the effective working storage capacity of the conveyor, and in some cases this may be very small or non-existent. For an exploration of this problem for a conveyor system already in place refer to (1).

USE OF A NOMOGRAPH TO TEST AN EXISTING CONVEYOR

The principal problem involved in computing the system parameters is that their computation involves the solution of several simultaneous equations. As an aid in such computational work, a short cut method of examining an *existing* conveyor system under a specific set of conditions is available using the nomograph shown in Figure 2 to find candidate workable revolution times. However, these candidate workable revolution times are not guaranteed to be workable revolution times. The only practical test of such candidate workable revolution times is through the use of a simulation of the conveyor operation as outlined. However, if one does not wish to go through the simulation procedure, this short cut method will produce candidate revolution times that may be much closer to good revolution times than those determined by intuition or random selection. It may also point out that the system in place is unworkable for the proposed schedule set and put you on the trail of schedules that are more probably workable. The following outlined procedure is illustrated on the nomograph.

1. The conveyor length is known, as are the maximum and minimum technological velocities. The minimum technological velocity is the velocity that just provides parts spaces at the loading rate R_L or the unloading rate R_U whichever is the larger. Draw a line from the conveyor length through the maximum technological velocity point to the revolution time scale (Line *A*). Draw a second line through the minimum technological velocity point to the revolution time scale (Line *B*). This determines usable range of revolution times, and is based on the equation $W = L/v$.

2. Specify a producing system schedule and plot it cumulatively on a graph as shown on Figure 3. Specify a using system schedule on transparent paper to the same scale and lay it over the producing system schedule so that it touches the producing system schedule at one point. This point is the minimum inventory point. Determine the point at which the maximum inventory occurs by scaling off the inventory build-up. The time between the minimum inventory point and the maximum inventory point is called the net gain time T_L. Examine the two curves to determine the length of one overall production cycle, the time period over which the planned schedule repeats. This is called the cycle time T.

Reference (1) indicates the following equations:

$N_T T = N_W W$, where N_T and N_W are integers. Eq. 1.
$N_T T L = N x W$, where $N x$ is an integer. Eq. 2.

Eq. 1. states that the conveyor revolution time must bear some integral fractional relationship to the overall cycle time. Eq. 2. states that the conveyor revolution time must also bear some integral fractional relationship to the net gain time.

On the nomograph are plotted a number of "work points." These work points represent these integral fractional relationships over the practical working range. Thus, to find revolution times that will satisfy both equations, draw a line from the cycle time point on the T and T_L scale to work points that cause the lines to fall within the working technological range of revolution times (Lines *C*). Draw other lines from the net gain time through the revolution time scale to work points that will cause this second set of lines to fall within the workable technological range of revolution times (Lines *D*). Any combination

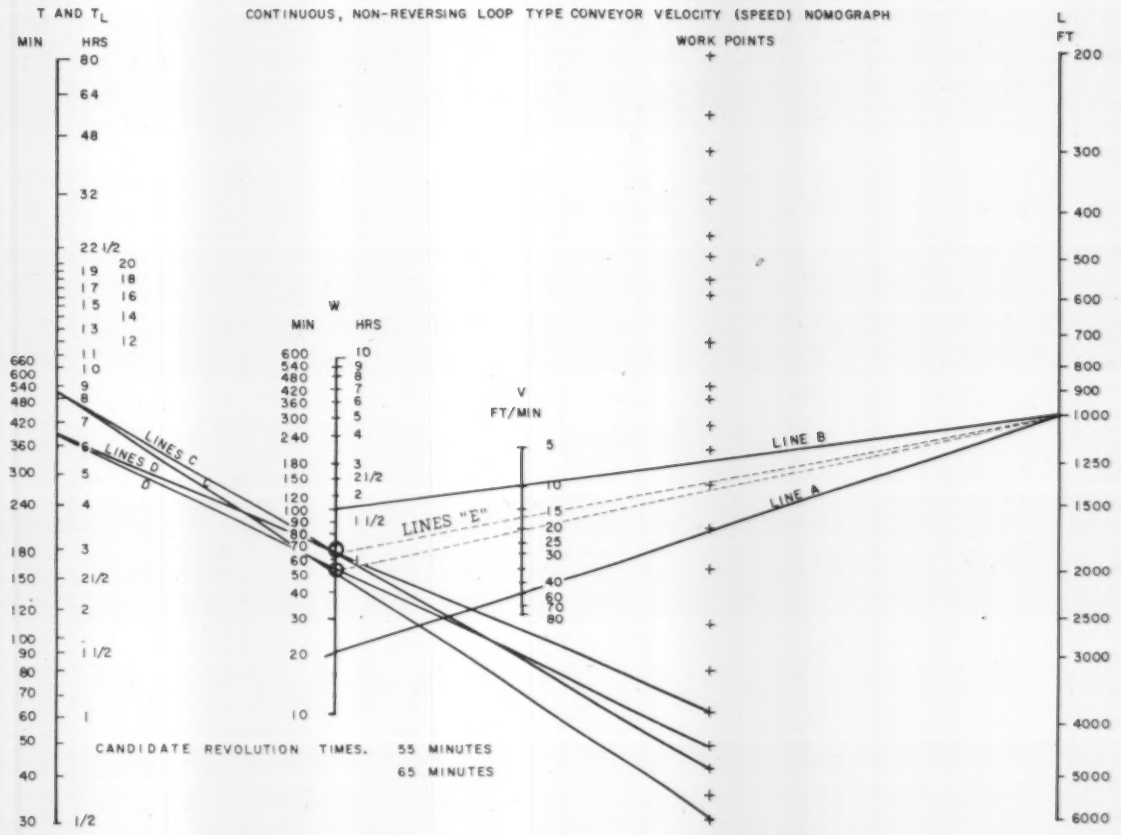

FIG. 2

of Lines *C* or *D* that intersect on or very close to the revolution time scale represent candidate workable revolution times. Connect these points of intersection with the conveyor length to determine candidate conveyor velocities (Lines *E*).

If one is using the simulation technique to check out the answers, these candidate revolution times can be submitted to the simulation test starting with the one with the smallest revolution time since this provides the largest usable storage capacity. If simulation is not used to prove out these candidate workable revolution times, they may be tested by actual operation of the conveyor, and certainly revolution times so determined will be better than randomly determined revolution times. This revolution time should be used to determine if the required storage capacity is available after assigning accessibility reserves, ignoring the discontinuity reserve if simulation is not done. If simulation is done, it will indicate and take into account the discontinuity reserve.

It can easily happen that *no* candidate revolution times are found. This will indicate that the combination of schedules and conveyor system characteristics are unworkable and other schedules should be tried until one or more workable solutions is found.

CONVEYOR SYSTEM DESIGN

The conveyor design problem need not have a solution so precise as that required for an operating condition, but the conveyor should be designed with characteristics that permit it to handle a reasonable range of schedule combinations effectively. To solve this problem, first determine the technological characteristics of the conveyor system, including number of parts per carrier, carrier spacing, and maximum and minimum technological velocities.

1. Determine probable alternative schedule sets that may be

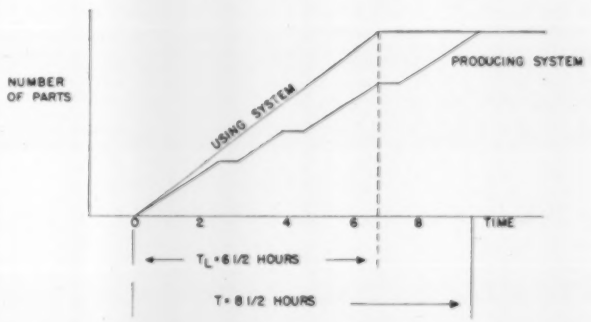

FIG. 3

imposed on the system after it is in use. From these determine the cycle time, net gain time and total desired inventories (planned plus safety reserves).

2. From the above information determine the conveyor lengths to the next largest full number of carriers.

3. Use the maximum technological velocity and this conveyor length (recognizing that it is too short because it does not allow for accessibility reserves) to determine the minimum revolution time. Calculate the accessibility reserves $W\ (R_v + R_L)$. Now calculate a new conveyor length adding reserves to basic planned inventory and recalculate revolution time and reserves until the increase in conveyor length per try is less than one additional carrier and round off to the next highest full carrier.

4. Use the nomograph as outlined earlier to determine whether there are candidate workable revolution times for each anticipated schedule set. Test these candidate workable revolution times on the simulator.

5. Select the longest indicated conveyor length, rejecting some of the schedule sets if they indicate excessively large additions to conveyor length, knowing in advance that these may be unworkable in the future except under very special conditions.

6. Test all remaining schedule sets using this length to determine if there are still candidate workable revolution times available. Test these candidate workable revolution times on the simulator.

The chances are very good that all schedule combinations calling for a shorter conveyor than the one selected will have at least one workable revolution time.

SUMMARY

Through the use of this kind of cut and try procedure it is possible to understand more completely the functioning of any proposed conveyor system in advance of its installation, and using the procedure without simulation to estimate length and compare rather quickly the cost of this kind of closed loop conveyor system with other alternative systems, thus assuring application of such systems to situations for which they are suited with higher levels of confidence than was possible formerly.

This same procedure can be used for multiple part conveyors, those storing and delivering more than one part or part type. The problem here is to find candidate workable revolution times that are common to all the parts systems the conveyor links. Quite obviously, as the number of different parts on the conveyor goes up the less likely it is that common candidate workable revolution times can be found. These common candidate workable revolution times can be tested with the simulator by treating each part system as a completely separate conveyor system. They cannot, however, be treated separately in finding candidate revolution times.

With the techniques outlined, almost any type of closed loop conveyor system can be planned and tested for operation under varying conditions with a reasonably high assurance that after the investment has been made, or after a particular schedule set has been selected, the conveyor or system will do its intended job satisfactorily.

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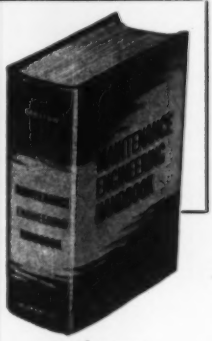

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by RALPH F. HUTH

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OBSERVATIONS recorded as ratios, percentages, or proportions, are commonly referred to as attribute or "all or nothing" type data. Transforming such data into normalized forms often is time-consuming and requires considerable statistical knowledge.

Much of the information collected and recorded during processing operations in a steel plant is of the attribute type. Careful examination and analysis of this information even though it may be an "after the fact" or "hindsight" approach, often leads to interesting and useful conclusions.

The method presented in this article is aimed specifically at the analysis of process data. The process data are searched or examined by the technique presented for meaningful relationships that may be helpful in improving quality or costs on future processing. Granted, it is better to look to the future in the form of designed experimentation utilizing controlled data collection conditions, but this is not always economically possible, and we cannot afford to ignore information which has already been gathered.

METHOD

Factorial Chi-Square first became known to the writer in 1956 at the Montreal National Convention of the American Society for Quality Control. A paper presented by Herbert C. Batson (1) aroused sufficient interest to apply the technique to a current problem with encouraging results. Since then the approach has been used on several other problems, with considerable success.

The basic Chi-Square formula generally appears as follows:

$$\chi^2 = \frac{\sum (E - 0)^2}{E} \qquad \text{Eq. 1.}$$

where E is the expected occurrence and 0 is the observed occurrence.

Let us apply this to the following problem. The lost time accidents for a given year were distributed by shifts as follows:

First shift = 4
Second shift = 13
Third shift = 13

Not knowing hours worked per shift or working condition differences, we assume that the opportunity for accident occurrence should be equal for each shift. Translating this into the terms of our problem our expected occurrence for each shift becomes 10. Solving for Chi-Square with 2 degrees of freedom we get the following:

$$\chi^2 = \frac{(10-4)^2}{10} + \frac{(10-13)^2}{10} + \frac{(10-13)^2}{10}$$

$$= 3.6 + .9 + .9 = 5.4$$

Our hypothesis is that there is no difference in lost time accident occurrence by shifts. Looking in a table of Chi-Square values for 2 degrees of freedom we find Chi-Square .05 is 5.99. We therefore are likely to conclude that there is insufficient evidence for the rejection of our hypothesis even though it may appear that the first shift has a tendency to have fewer accidents.

Supposing our combined results for a two year period had been as follows:

First shift = 8
Second shift = 26
Third shift = 26

Assuming the same conditions as in the foregoing example we would expect 20 lost time accidents per shift. The Chi-Square calculation then becomes:

$$\chi^2 = \frac{(20-8)^2}{20} + \frac{(20-26)^2}{20} + \frac{(20-26)^2}{20}$$

$$= 7.2 + 1.8 + 1.8 = 10.8$$

Our hypothesis that the accidents occur without bias by shifts is rejected at the .01 level of risk. (Chi-Square .01 for 2 degrees of freedom is 9.21.)

From the two foregoing examples we see that Chi-Square is affected by sample size, just as are most statistical procedures.

Table 1 gives a simple example of the use of Factorial Chi-Square. The illustrated problem deals with a fatigue bend test wherein a piece of metal is flexed a given number of times and if a crack or breakage occurs, the test piece is regarded as a failure. Two types of steel and two methods of processing are used as the variable factors. The data used are for specimen purposes only.

Using the Brandt-Snedecor formula (Eq. 2.) the total Chi-Square with 3 degrees of freedom is found to be 14.27.

$$\chi^2_{(k-1)} = N^2/(S \times F) \times SS \qquad \text{Eq. 2.}$$

where

k = number of subgroups
S = number of successes

* Based upon a presentation to the Calumet Chapter Conference on April 6, 1960.

TABLE 1

Factorial Chi-Square Analysis

Steel type	A		B	
Processing Method	I	II	I	II
Successes	31	17	26	26
Failures	4	18	9	9
Number of Tests	35	35	35	35

$$\text{Chi-Square 3° of Freedom} = \left(\frac{140^2}{100\times 40}\right)\left(\frac{31^2}{35}+\frac{17^2}{35}+\frac{26^2}{35}+\frac{26^2}{35}-\frac{100^2}{140}\right)=14.27$$

Steel Type	A		B							
Processing Method	I	II	I	II						
Successes/35	31	17	26	26	Σ+	Σ−	D	D^2/N	$N^2/S\times F$	χ^2
Steel	+	+	−	−	48	52	−4	.114	4.9	.56
Method	+	−	+	−	57	43	14	1.400	4.9	6.86
S×M	+	−	−	+	57	43	14	1.400	4.9	6.86

$\chi^2_{.01}$ 1 degree of freedom = 6.64 — Total $\chi^2 = 14.28$

F = number of failures

N = total number of samples

$SS = (s_1^2/n_1 + s_2^2/n_2 + \cdots + s_k^2/n_k - S^2/N$

Little s and n are the successes and number of samples respectively in each subgroup.

Eq. 2. is much faster than Eq. 1. and yields the same results within rounding error. In this instance Eq. 1. gives Chi-Square = 14.28 with no rounding error.

The lower portion of Table 1 utilizes the Factorial Chi-Square approach as outlined by Batson in the 1956 transactions. By this method the Chi-Square contribution of each effect is readily known and an independent assessment of the significance of each effect is made.

Table 2 gives an example of the application of this method to a 2^3 factorial design; an eight cell pattern using the three factors each at two levels. The computations are the same as shown in Table 1. The interaction which is obvious in Table 1 is not as easily seen in Table 2 until some of the computations are completed. In fact, there might have been a tendency to conclude that there was nothing significant in the data if only a total Chi-Square had been computed, as Chi-Square .01 for 7 degrees of freedom is 18.48.

This then, is the basic Factorial Chi-Square technique. Next, let us adapt the method to some of the process problems of industry which invariably involve unequal cell sizes when arranged in factorial pattern.

Table 3 gives an illustration of data of this type—unequal cell sizes. Again the data are for specimen purposes only by are indicative of typical steel problems. The successes represent the band or O.K. edges of approximately 1500 Hot Rolled Coils. The failures are edges that have cracked sufficiently to cause trouble in future processing. The three variables are chemical components of the steel broken into a high (+) and low (−) range. A typical analysis procedure might work as follows:

Step One

Record all data on Punch Cards.

Step Two

Find the midpoint of each variable and use this as the breaking point for determining high (+) and low (−) values.

Step Three

Factorially sort the cards into the eight cells or combinations required by a 2^3 factorial pattern. On a problem with a relatively small number of cells such as in the example, conventional tab sorting equipment would suffice. However, if the number of cells were larger, 16, 32, 64 and on up, an I.B.M. 101 Statistical Machine would do a rapid job and give actual printed listings. 1500 cards could be broken into a 2^6 factorial pattern with 32 cells in less than 5 minutes, provided the board wiring was done ahead of

TABLE 2

2^3 Factorial Chi-Square

Factor													
A	+	+	+	+	−	−	−	−					
B	+	+	−	−	+	+	−	−					
C	+	−	+	−	+	−	+	−					
S/25	12	13	17	8	8	17	13	12	Σ+	Σ−	D^2/N	$N^2/S\times F$	
							A	Effect	50	50	0	4.00	0
							B	Effect	50	50	0	4.00	0
							C	Effect	50	50	0	4.00	0
							AB	Effect	50	50	0	4.00	0
							AC	Effect	58	42	1.28	4.00	5.12
							BC	Effect	40	60	2.00	4.00	8.00
							ABC	Effect	50	50	0	4.00	0

$\chi^2_{.01}$ 1 degree of freedom = 6.64. — Total $\chi^2 = 13.12$

TABLE 3

2^3 Factorial Chi-Square with Unequal Cell Sizes

A	Copper	−	−	−	−	+	+	+	+
B	Sulphur	−	−	+	+	−	−	+	+
C	Silicon	−	+	−	+	−	+	−	+
	S	166	118	108	70	110	61	133	88
	f	49	32	35	71	70	91	94	202
	n	215	150	143	141	180	152	227	290
	Ratio*	109	111	106	70	86	57	83	43

Effect	Σ′−	Σ′+	D′	D′²	D′²/N′	N′²/S′×F′	$\chi^{2\prime}$
A	396	269	−127	16129	14.30	4.13	59.09
B	363	302	− 61	3721	3.30	4.13	13.63
C	384	281	−103	10609	9.41	4.13	38.86
AB	346	319	− 27	729	.65	4.13	2.68
AC	315	350	+ 35	1225	1.09	4.13	4.50
BC	308	357	+ 49	2401	2.13	4.13	8.50
ABC	319	346	+ 27	729	.65	4.13	2.68
							130.21

$\chi^2_{.01} = 6.64$ $\quad N' = 1128$ $\quad S' = 665$ $\quad F' = 463$

$\chi^2_{.001} = 10.83$ $\quad N = 1498$ $\quad S = 854$ $\quad F = 644$

$$\text{Total } \chi^2 \text{ 7 degrees of freedom} = \frac{1498^2}{854 \times 644}\left(\frac{166^2}{215}+\frac{118}{150}+\frac{108}{143}+\frac{70}{141}+\frac{110}{180}+\frac{61}{152}+\frac{133}{227}+\frac{88}{290}-\frac{854}{1498}\right) = 190.86$$

* Ratio of successes to total of smallest cell (141).

time. However, once a 2^5 board has been prepared additional 2^5 runs could be made with relatively little board wiring time.

Step Four

Compute the total Chi-Square using Eq. 2.

Step Five

Compute the Factorial Chi-Square components using the method as shown in Table 3. In Table 3 the successes are reduced in the proportion of the cell size n to the smallest cell size, in this case 141. The ratios are rounded to the nearest whole number. The computations for Factorial Chi-Square are then made using the ratioed or prime values. N which equaled 1498 becomes 1128, S which was 854 becomes 665 etc. Naturally our total Factorial Chi-Square is now less than that of our total Chi-Square because of this manipulation.

Step Six

It now becomes necessary to interpret and use our results. By using the Factorial Chi-Square technique we find many of our effects are significant. However, action should not be taken just because Chi-Square indicates significance. The Chi-Square test of significance acts merely as a stop and go sign. If the sign says stop (no significance) we will not proceed, but just because it indicates go (significance) doesn't mean we must take action. In our example the effect of copper was very strong. Our estimates showed that better than a 20% improvement could be made if we worked only the low side of the copper range. Yet the cost of reducing copper in the steel might be prohibitive even if it could be done at all. The sulphur content possibly could be controlled, but would require some cost expenditure. We must then make a cost study to determine if reducing the sulphur would be economically feasible. Our best estimate is that an approximate 10% improvement would result if we worked to the low side of the sulphur range. Perhaps the silicon effect would be the cheapest to control and would afford the greatest improvement per dollar spent. The interaction BC, even though significant might not afford any increased benefits once the silicon is properly controlled. A proper examination of a 2-way table should help answer this question. Because corrective action is difficult or impossible on some of the effects does not mean we should ignore these indications in future experimentation, rather, we should use the knowledge by properly designing future work so that these effects do not cloud the appraisal of other economically manageable effects.

TABLE 4

Computer Programming of Factorial Chi-Square

I	A. Frequency Distribution. B. $\bar{X}$ or Average. C. σ or Standard Deviation.
II	Frequency Distribution vs. Percent Successful.
III	Optimum Break Points for Variables.
IV	Total Chi-Square.
V	Factorial Chi-Square.
VI	Percentage Effect of Each Cell or Pocket.

USE OF HIGH SPEED COMPUTERS

Attempts have been made to program portions of the Factorial Chi-Square technique on high speed computers. Probably the greatest benefit occurs in the selection of break points for the determination of high and low groupings. The computers can select the break points so that the smallest cell size is a maximum. Table 4 shows a step by step procedure for a proposed computer program utilizing Factorial Chi-Square. The steps of the program are as follows:

Step One

Prepare a frequency distribution and compute the average and standard deviation of each variable.

Step Two

Plot the percentage of successes for each increment of the frequency distribution for each variable. This enables a crude check for serious departures from linearity.

Step Three

Determine the optimum break points for each variable so that the smallest sample size will be a maximum. In the actual running of a problem minimum cell size limits are given the computer and if this minimum is not met, predetermined variables are automatically dropped until such time as the original minimum pocket size is met.

Step Four

Calculate the total Chi-Square using Eq. 2.

Step Five

Calculate the Factorial Chi-Square components using the smallest cell sample size as a basis for the computations (same method as Table 3).

Step Six

Calculate the percentage effect of each cell for use in interpretation of results. The percentage calculations can be of help in presenting the data to management and can help answer the question of the percent improvement that can be expected under various processing condition combinations.

SUMMARY

Some of the computational details of Factorial Chi-Square are presented. In addition a technique for handling unequal sample sizes is presented along with a program outline for high-speed computers. While the outlined procedures will yield a Chi-Square value that can be tested for significance, the occurrence of a significant value is not always cause for corrective action. Tempering the results with good judgment will enable the experimenter to use this technique on many attribute type problems. The ease and speed of the calculations should be of benefit to any experimenter or analyzer who is interested in quick approximations with fair reliability on attribute-type data problems. It is again emphasized that the Chi-Square test of significance is used only as a guide, supplementing good judgment.

In using unequal sample sizes the total Factorial Chi-Square significance level will always be less than the total Chi-Square value for the problem. If the total Factorial Chi-Square value is considerably less than the total Chi-Square value, it is an indication that the sample sizes are out of proportion to each other. If the sample sizes are approximately equal and the minimum sample size is 20 or 25, the method should work quickly and satisfactorily.

REFERENCE

(1) Batson, H. C., "Applications of Factorial Chi-Square Analysis to Experiments in Chemistry," *National Convention Transactions, American Society for Quality Control, 1956*, pp. 9-23.

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A Test of Two Assumptions Made in Job Evaluation

by **THOMAS E. BARTLETT**

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THE VALUE of one job in an organization in relation to that of another job and the methods of determining the job value are important to both management and the worker. Many phases of personnel and industrial relations activities are made far less effective when the wage and salary structure of a company is subject to criticism. Although dissatisfaction may stem from other sources, two major sources are the absolute and the relative rates paid (3).

The absolute amount of pay refers to the actual rate of pay in dollars and cents. This rate determines the employee's standard of living. The relative rate of pay refers to the rate earned by an employee in relation to the rate earned by other employees. An employee may be satisfied with his absolute rate of pay until he learns about his relative rate of pay, that is, there may be a fellow employee who receives a higher rate for comparable work where there appears to be no real difference between the merit of the work done or the length of service on the job.

There is no magic formula for establishing absolute and relative rates of pay or of minimizing the type of pay inequities which may exist. Neither is there a scientific solution, since no problem of human affairs is yet subject to the exact laws of science. However, a systematic approach—the use of job evaluation—has been developed, and this method provides a useful solution for many of the wage and salary problems.

PURPOSES OF STUDY

Any system which is to operate effectively ordinarily pre-supposes or assumes that certain conditions within the system are "normal." Job evaluation is no exception. One of the purposes of this study was to test the validity of two of the major assumptions under actual conditions. The two assumptions to be tested were that the job *structure* or content is internally consistent within the labor market and that once it is established it is independent of time and the geographic location. If this assumption regarding time is true, then a wage rate for a job can be predicted for any time period. For example, the wage rate of a nurse in Chicago for 1953-1954 could have been predicted if the wage rate of a nurse in Chicago for any other year, say 1951-1952, had been known and the wage rate of any other job in Chicago, say that of a carpenter, had been known for both of the two years. This can be seen more clearly from Figure 1. If three wage rates are known the fourth can be predicted. In the same manner, if the assumption regarding the geographical location is true, then the wage rate for a job in a city for a particular year can be predicted.

The second purpose of the study was to observe the correlation between the estimates of the true ranking of all the jobs for any two periods. If the coefficient of correlation is high, then it can be said that though the actual wage rates change with time the relative rank of the job remains the same.

With these objects in mind, the wage rates for ten different jobs in eight cities were obtained for 1951-1952, 1952-1953, 1953-1954, 1954-1955, 1955-1956. The jobs selected were Payroll Clerk, Office Boy, Secretary, Switchboard Operator, Nurse, Carpenter, Machinist, Order Filler, Receiving Clerk and Janitor. The cities chosen were Newark-Jersey City, New York, Philadelphia, Atlanta, Chicago, Denver, Los Angeles, and San Francisco.

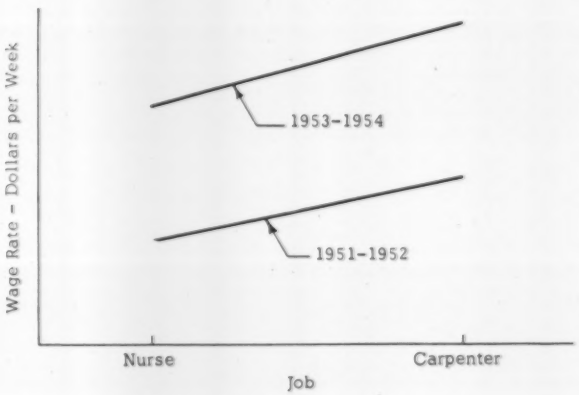

FIG. 1

TABLE 1

Analysis of Variance—Technique A

Source	Sum of Sq.	D.f.	Mean Sq.	F	$F_{.01}$
Job	57,430.22	9	6381.1	368.42*	4.355
Year	9,225.83	4	2306.4	133.16*	5.695
City	8,443.545	7	1206.2	69.64*	13.51
Job×city	2,216.605	63	35.2	2.02*	1.65
Year×city	162.735	28	5.8	.335	2.12
Job×year	337.260	36	9.4	.543	1.93
Job×year ×city	4,364.335	252	17.32		
Total	82,180.53	399			

* No significant results.

TECHNIQUES EMPLOYED

There were two techniques employed in this study. One concerned itself with the wage rate expressed in terms of dollars per week (Technique A); whereas, the other concerned itself with the wage rates expressed in terms of percentage, with the wage rates of all the jobs for 1951-1952 considered as 100 (Technique B). If the two techniques do not yield identical results, the technique which more closely corresponds to the empirical data might be considered as the better.

To analyze the variation in the wage rates, an analysis of variance test was made to determine the source of variation. There were three main effects, namely, year, job, and city. The three main effects were expected to introduce significant variation. If, on the other hand, the variation due to the interactions can be shown not to be significant, the two previously discussed assumptions can be shown to be valid and used in the job evaluation procedure with some confidence.

To obtain the coefficient of correlation between the true ranking of all the jobs for any two periods, the jobs were ranked in all of the cities for those two periods. The best estimate of the true ranking could then be made for the two periods in question and the coefficient of correlation could be obtained. The coefficient of concordance (2) can also be found to indicate the agreement between the cities on job rankings. A test of significance of the coefficient of concordance can then be made to determine whether the value of the coefficient obtained was due to chance.

EXAMINATION OF DATA

Before discussing the results of the study, it seems appropriate to examine the data and the assumptions made. The data and job descriptions for this experiment came from the bulletins published by the Bureau of Labor Statistics (5). The technique employed in collecting the data is discussed by Samuel E. Cohen in his article, "Studies of Occupational Wages and Supplementary Benefits" (1). The reader who is interested in this method of survey is referred to that article.

Those wage rates which were included in this study, were so chosen because the data were available in this combination of ten jobs, eight cities and five years. The wage rates represent the average wage rate in the manufacturing industry only. They do not represent wage rates of a single plant. The year 1951-1952 represents October, 1951, to March of 1952 in order to eliminate increase in labor during summer months. The cities represented the major geographic regions of the United States, namely, East, South, Midwest and the far West. (It would have been more desirable if one more city for the South and the Midwest could have been included.) The ten jobs were broken down into two categories: salaried and hourly paid jobs. The hourly-paid jobs were further broken down into two classes: skilled labor and maintenance labor.

The following assumptions are made regarding the data:

1. The normal work week consists of forty hours.
2. The working conditions associated with each job in the different cities, over the period of five years, remain relatively uniform without significant variation.
3. The requirements of a job, such as mental ability, physical ability, and skill, remain relatively uniform.
4. A certain number of fringe benefits are offered with each job.
5. If the job content for a specific job is changed it is excluded from the survey.
6. The organizations involved in the survey pay the "going rate" to their employees.

The variation in the wage rates was analyzed by the analysis of variance technique. This technique breaks down the total variation into components and the *F*-test determines if this variation is due to chance causes alone.

Table 1 and Table 2 were obtained from the original data of 400 observations.

Looking at the results of the analysis of variance for the Technique A, it is seen that there are four factors which introduce significant variation. These factors are job, city, year, and the interactions between them. The *F*-test indicates that the variation which can be attributed is not due to chance causes alone. The results do not show that there is no variation due to the interaction between job-year and city-year but the *F*-test does indicate that this variation can be attributed to chance causes. This means that the variation in the wage rates is not the same for all the jobs. Jobs vary differently. Also, the wage rates for a job do not vary in the same manner in all cities. For example, in San Francisco, the wage rate for a machinist may increase by five dollars a

TABLE 2

Analysis of Variance—Technique B

Source	Sum of Sq.	D.f.	Mean Sq.	F	$F_{.01}$
Job	.020600	9	.00228889	2.519	4.355
Year	2.497180	4	.624295	687.13*	5.695
City	.039170	7	.0055957	6.159	13.51
City×year	.055546	28	.0019838	2.183*	2.12
Job×year	.032892	36	.00913667	10.056*	1.93
Job×city	.371222	63	.00589241	6.485*	1.65
Job×city ×year	.228956	252	.0009086		
Total	2.245566				

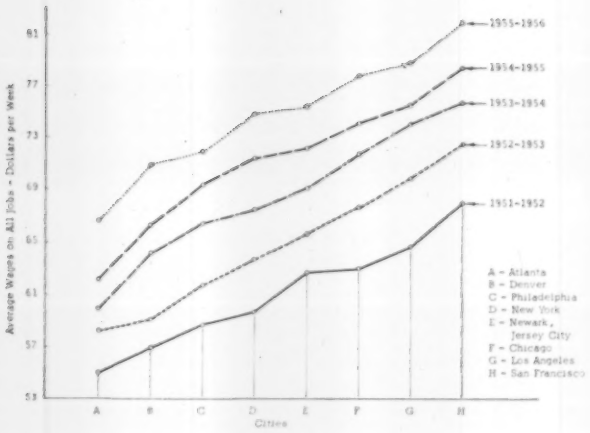

FIG. 2. City-Year Interaction, Technique A.

week, whereas in Atlanta the same wage rate for the same job period may only increase by two dollars a week. The wage rate for a job in a city may vary differently for different years. One year it may increase and the other year it may decrease. The interactions for Technique A are shown in Figures 2, 3, 4.

In the case where interaction is not significant, e.g., job-year, there are five almost parallel lines representing five years. They are not exactly parallel since there is some variation present due to chance. In this case, it is not difficult to predict a wage rate. The same is true of the city × year interaction, whose graph is not shown. In the graph of the city-year interaction the lines for five periods are not parallel and intersect at many points. Hence predictions are almost impossible.

Looking at the analysis of variance table for Technique B, all three interactions introduce significant variation which cannot be attributed to chance causes alone. If the interactions are plotted on a graph, the curves are not parallel and in some cases, they may even intersect many times as in Figure 4. Hence, predictions would be almost impossible. The above statement was verified in the study where these interactions were plotted on a graph.

On comparing Techniques A and B, it appears that Technique A, which represents the change in wage rate in terms of dollars per week, is a much superior technique for this type of study. In Technique A, some predictions regarding wage rates are possible, whereas, in Technique B, all the interactions are significant and predictions are almost impossible.

To achieve the second purpose of the study, that is, to obtain the coefficient of correlation between the ranking for any two periods, the jobs in each city were ranked for three periods, 1951-1952, 1953-1954, 1955-1956 and the coefficient of concordance and the Spearman coefficients were established by the method shown by Kendall (2). Coefficient of concordance is defined as the degree of agreement between different observers, in our case, the cities. The Spearman coefficient determines the same result by a different method. A significance test was made at the one percent level on the coefficient of concordance and then the best estimate of true ranking for a year was made. The coefficient of correlation between these three years' estimated ranking was then determined and the significance test made. (See Table 3.)

All three coefficients are quite high and do not indicate a significant amount of change. All three coefficients were found to be significant at the one percent level, which indicates that there is a definite relationship between the rankings of three years and that they do not occur by chance causes alone. The Spearman coefficient is also seen to be high.

TABLE 3

Best Estimate of True Rankings

1951–1952	1953–1954	1955–1956
1. Office Boy	1. Office Boy	1. Office Boy
2. Janitor	2. Janitor	2. Janitor
3. Switchboard Operator	3. Switchboard Operator	3. Switchboard Operator
4. Order Filler	4. Order Filler	4. Order Filler
5. Receiving Clerk	5. Receiving Clerk	5. Receiving Clerk
6. Secretary	6. Secretary	6. Secretary
7. Payroll Clerk	7. Nurse	7. Nurse
8. Nurse	8. Payroll Clerk	8. Payroll Clerk
9. Carpenter	9. Carpenter	9. Carpenter
10. Machinist	10. Machinist	10. Machinist

The coefficient of concordance was found to be as follows:

Year	Coefficient of Concordance	Spearman Coefficient
1951–52	0.919	0.907
1953–54	0.909	0.896
1955–56	0.903	0.886

Looking at the best estimates of the true ranking in these three years, the rankings seem to remain unchanged, except in the case of the nurse category, which is seen to move from eighth place in 1951-52 to seventh in 1953-54 to sixth in 1955-56. This means, of course, that the average rate of pay for a nurse has decreased over the period of five years in relation to other jobs. The coeffi-

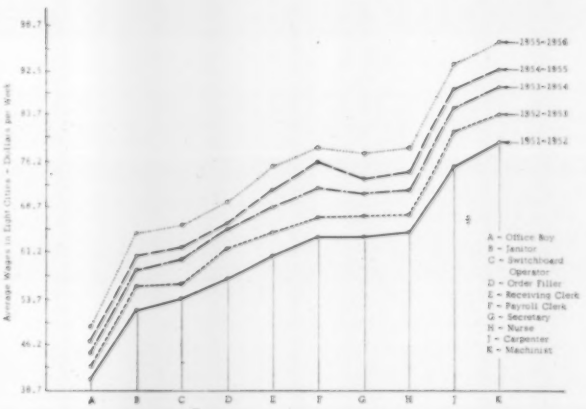

FIG. 3. Job-Year Interaction, Technique A.

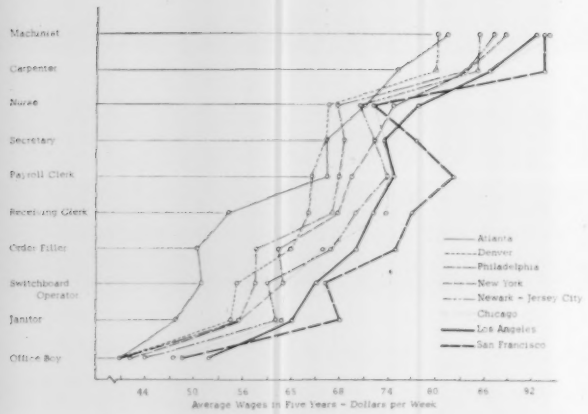

FIG. 4. Job-City Interaction, Technique A.

cient of correlation between the best estimate of true rankings for the years 1951-52 and 1953-54 was found to be .98 and for 1953-54 and 1955-56, the coefficient of correlation was also seen to be .98. The two years 1951-52 and 1955-56 were related by a coefficient of correlation of .96.

CONCLUSIONS

It can be concluded from the analysis of variance test that Technique A, which expressed the wage rates in terms of dollars per week, was a better technique for predictive purposes. When wage rates were expressed in terms of dollars per week, the assumption, which stated that the job structure is internally consistent and once established is independent of time, was found to be valid. The prediction of a wage rate can be made in terms of year and job. The second assumption regarding the independence of wage structure with respect to geographic location was not valid because a significant interaction was observed between the cities and the jobs. Consequently, wage rates could not be predicted in terms of geographic location and jobs. This becomes obvious in the light of the fact that unions, at the bargaining table, usually demand a specific increase in wages in terms of dollars per week rather than a percentage increase.

The results of the rank correlation data revealed a high degree of correlation between the best estimate of true ranking of two periods. It may be concluded that the job ranking system of job evaluation should yield significant results. The job ranking method is simple to understand and easy to install and, hence, it should be considered more frequently than it is at present. A high degree of agreement between the cities in the ranking of jobs supports the foregoing conclusion.

In this study, two of the assumptions made in job evaluation were tested for their validity, using a relatively small amount of data. It is recommended that the assumptions regarding the data should also be tested. It is also recommended that a similar study in one particular industry be made and that a replication of this study be made for a greater number of jobs, cities and time periods. Job evaluation is a field requiring much research and development and all of the hypotheses will have to be tested under actual conditions before the system can be accepted without considerable qualification.

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A New Model for Work Sampling—the GREDS Theory

by **JOHN J. HALSEY**[1]

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THE POPULARITY and utility of work sampling has been well established. Activity of men, machines or other operations can usually be measured at lower costs by work sampling than by other techniques.

In many cases reported in the literature, the mathematical basis for work sampling is a simple binomial model (1), (7), which requires a randomization of observations. Yet frequently, a route system is used. Intuitively one might question the validity of precision estimates and the possibility of bias if the sampling practice deviates from the theoretical model being used.

A route system by its very nature implies something less than complete randomness. The difficulty becomes most apparent in the study of people not assigned to fixed locations or fixed tasks. This factor of personnel mobility can present a problem in work sampling in a plant covering a large geographical area, having multistory buildings along with natural and man-made barriers such as railroads, rivers or highways.

It was this sort of situation that stimulated a search for models other than binomial. The objective was to develop a general framework for the more complex situations, achieve greater precision if possible, and retain simplicity in procedure for practical application.

The model presented here is in fact more general, has greater precision or greater validity, and is simpler in application in the field. While the method involves the somewhat more complicated mathematical formulas of the Ratio Estimate, this is believed to be a small price to pay for the other gains achieved. The theory of the Ratio Estimate has been used in survey work and has also been applied to the sampling of physical materials.

[1] The author wishes to thank Dr. W. E. Deming of N. Y. U. for his helpful comments on the manuscript, and particularly for his suggestions on simplified computations. Mr. Gunther Slaton of General Foods rendered indispensable assistance in criticizing early drafts, and in pointing out many of the practical problems in the field. The generous assistance and cooperation of the personnel at the Atlantic Gelatin Division, and the Walter Baker Division of General Foods Corporation in executing these techniques in actual practice was helpful for the clarification of many points in this article.

A REVIEW OF SOME ASPECTS OF THE PROBLEM

The simple binomial model has been recommended and used in much of the work sampling reported in the literature. In order for this model to be applicable, the observations must be taken in a random fashion. Randomness, the basis for the binomial model, implies: first, that any item selected from the population being studied is completely independent of every other item; and secondly, each item selected from the population has an equal probability of being selected from all the items. Most authors stress the importance of randomness of observation times.

Deming (4) in describing probability samples, states that the interviewer or observer and the elements in the sample should have no discretion about who is in the sample. The selection of the individual to be observed should be defined by the rules and the interviewer should have no choice in the matter. Unless this is so, probability theory cannot be used to evaluate the precision of the results.

Heiland and Richardson (7) point out that the reliability of work sampling data depends primarily upon the number of observations *if* the observations were taken under random sampling conditions. These authors suggest that a continuous evaluation of reliability be made as the study progresses.

Conway (3) comments on the practice of taking several observations at a time and the adverse effect this has on the assumption of randomness when using the binomial model. This, he cautions, results in a variance estimate lower than the true value. Conway gives formulas for estimating variance using a stratified model.

In this article a practical system for coping with the aforementioned difficulties is given and a new model is suggested. The new model using a superior method of estimation and assured randomness gives a valid estimate of precision usually with gains over the binomial.

The system outlined is based on experiences in several locations with different organizations in both structure and function. It was felt that a broader concept could be developed by expressing the model in general terms rather than the more restricted specific application. It will be appropriate to follow this initial article with specific cases.

THE IDEAL BINOMIAL MODEL

In order to demonstrate the new approach it is useful to start with the familiar binomial model for comparison. A physical analogy for the binomial is easily demonstrated by an "ideal bowl" experiment. Visualize 24,000 beads in a bowl, 25% of them colored and the remaining 75% white.

If one drew a sample of 50 beads, one at a time with

POPULATION		A SAMPLE		
Person	Time	Unit	Bead Identity	Random Beads
AA	8:30 AM	1	○	
	8:31	2	●	●
	8:32	3	○	○
	.	.		
	4:30 PM	480	●	
BB	8:30 AM	481	●	
	8:31	482	●	
	.	.		
	9:06	517	○	○
	.	.		
	4:30 PM	960	●	
CC	8:30 AM	961	●	●
	8:31	963	○	
	.	.	○	○
	4:30 PM	1,441	○	
	.	.		
YY	.	.		
	.	.		
	.	.		
	8:30 AM	22,081	○	
	8:31	22,082	●	
	.	.	○	
	4:30 PM	22,560	○	
AX	8:30 AM	22,561	●	
	8:31	22,562	○	○
	.	.	●	●
	4:30 PM	23,040	○	
AY	8:30 AM	23,041	●	
	8:31	23,042	●	●
	.	.	●	●
	4:30 PM	23,520	○	
AZ	8:30 AM	23,521	○	
	8:31	23,522	○	○
	.	.	●	
	4:30 PM	24,000	●	

FIG. 1. A Diagram Illustrating a Population, Identifying People and Time as Unequivocal Units and Showing a Possible Sample from this Population.

replacement, one could estimate the percentage of colored beads in the bowl. The proportion colored would be estimated by the binomial formula.

$$\hat{p} = \frac{r}{n} \qquad \text{Eq. 1.}$$

where

r = the number of colored beads,

n = the total number of beads in the sample.

The estimate of the standard error (standard deviation) would be calculated by the formula for a proportion:

$$\hat{s}_p = \sqrt{\frac{p(1-p)}{n}} \qquad \text{Eq. 2.}$$

If the estimate $\hat{p}$ can be assumed to be normally distributed about the population mean, and this assumption is adequate in most practical situations, then plus and minus three standard deviations about the mean will enable one to predict the limits of other samples from the same population. For testing hypothesis, or for minimizing some loss function, some other multiple of the standard deviation might be used, modified if necessary, for skewness. If p is small and the sample size is also small, one should be cautious about using the normal approximation. A good discussion of alternative modes of calculation of confidence limits is given by both Cochran (2) and Deming (4) as well as many other satisfactory texts. As n, the number of observations is increased, the random sampling error is successively reduced, if the samples are taken in a random manner. The estimate of the proportion, as n increases, follows the law of averages and gives closer and closer estimates of P, the true proportion of colored beads in the bowl.

BINOMIAL MODEL RELATED TO AN ACTUAL SITUATION

Relating the binomial model to the sampling of the activity of people, one might take the example of 50 people each working 8 hours or 480 minutes a day. This would give a total of 24,000 minutes, which may be represented in the ideal bowl by 24,000 beads (of two colors).

If each bead is now related to a single minute of a single person's day, one has a model for the actual binomial situation. By assigning beads 1 to 480 to man *A*, 481 to 960 to man *B*, 961 to 1440 to man *C*, etc., down to the last man who has beads 23,521 through 24,000 representing his day, each bead or unit is unequivocally identified with a man and a time. The sample from this population is selected by the use of a table of random numbers (from 00001 to 24,000).

If one had drawn number 517, for example, the random process would have selected man *BB* at 9:06 a.m. (the 36th minute of his working day, assuming the day began at 8:30 a.m.). This situation is illustrated in Figure 1 where the population being sampled is shown along with a possible sample. The procedure would be to locate man *BB* at 9:06 a.m. and instantaneously observe what he was doing.

While this procedure may appear complicated it does assure adherence to the binomial model and enables one to calculate valid standard errors. A selection procedure very similar to this is discussed by Rosander (9). In this model, men and time are randomized, geography is eliminated and the type of activity is determined. The binomial theory is applicable since the selection process is random. With people in relatively fixed locations, this technique for work sampling is very useful and will give valid estimates of P and Sp. However, the route system in ordinary use may not conform to this model, since there may be relationships between successive observations along the route. A judgment must then be made as to whether assumption of independence is valid. As soon as this is done the sample is no longer a probability but a judgment sample. While judgment samples are very useful they do not have calculable standard errors (4).

APPROACH TO THE NEW MODEL

The model to be described will start with an "ideal bowl." This will be extended to a physical model followed by a description of the theory, the necessary calculations, and some implications and uses of the data obtained by using this model.

The reality associated with the "ideal bowl" changes in this application as compared to the binomial.

Visualize first, an ideal bowl containing the colored and white beads, second, a sampling device (paddle) by which a sample of 50 random beads can be withdrawn and third, a box with low sides having dimensions of about 15″ × 15″ or 20″ × 20″, with the bottom covered by a suitable carpet material to prevent the beads from rolling, and marked off in 25 grids. Each grid is numbered in serial order from 1 to 25. See Figure 2.

MODEL ANALOGY AND FACTOR IDENTIFICATION

A demonstration would proceed along the following line.

1. Mix the beads in the bowl thoroughly.
2. Withdraw a sample of 50 beads from the bowl by means of a sample scoop.
3. Drop the 50 beads in a roughly randomly dispersed manner into the box, which is marked off into 25 identified grids. (The dispersion of the beads in the box is not critical as will be seen later.)

The factors under study involve: time, people, type of effort, and geography.

1. To account for time, consider the dispersed beads in the box as being a dispersion of beads at this instant in time.
2. Let each one of the fifty beads in the box represent a person. In this example, one would be studying a work force of 50 people.
3. The color of the bead represents the activity of the person, for example, colored is travel, white is not travel.
4. The geography of the plant is represented by the grids marked on the carpet, each grid being identified by a number on the Ideal Plant Model.

The result of what has been done up to this point can be represented by the situation shown in Figure 3.

One is now ready to make observations of the events represented by this physical model. Assume three observers are available at this instant in time, each of whom is in a position to observe one grid on the ideal plant model. These observers have each been provided with a random number between 1 and 25 (8). For example, 9, 15 and 17, the procedure is:

1. First observer locate grid Number 9.
2. Observe the total number of beads (people) in the grid and record.
3. Observe the color of the beads (activity) and record.
4. Other observers repeat the procedure simultaneously for grids 15 and 17.

Assume this instant in time has passed. Return the beads to the bowl. Scoop out a second sample of 50 beads, and repeat the procedure of dumping, observing, recording, etc. Each repetition of the procedure represents a new instant in time.

SUMMARY AND CALCULATION OF DATA

While one would not perform the summarization and calculations indicated below on so few data, the example is given for illustrative purposes.

The results of the data obtained might be set down as follows:

Grid Number	*Total Beads Observed in Grid* (x_i)	*No. of Colored Beads* (y_i)
9	2	0
15	1	1
17	1	0
Totals	$\sum x_i = 4$	$\sum y_i = 1$

The fraction of colored beads would be calculated by the following formula:

$$f = \frac{\sum y_i}{\sum x_i} = \frac{1}{4} = 0.25 \qquad \text{Eq. 3.}$$

This is comparable to the result one would have obtained using the binomial formula, although the binomial is inappropriate for this situation.

$$p = \sum \frac{r}{n} = \frac{1}{4} = 0.25 \qquad \text{Eq. 4.}$$

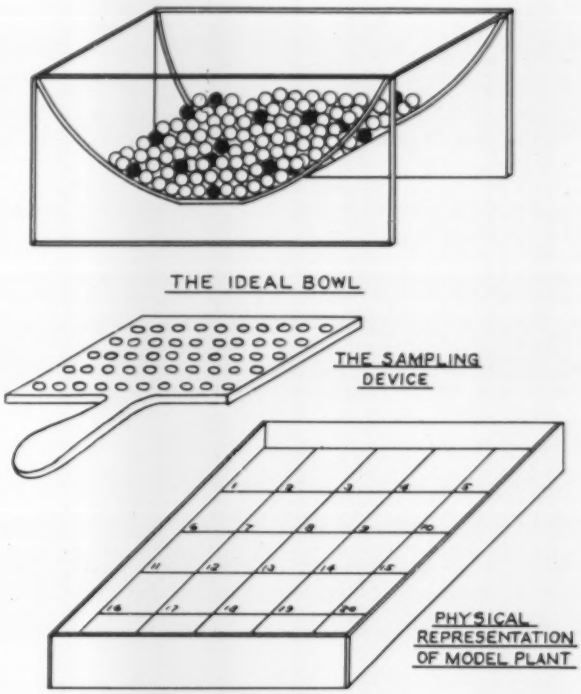

FIG. 2. A Diagram Illustrating the Tools Used to Demonstrate the New Approach.

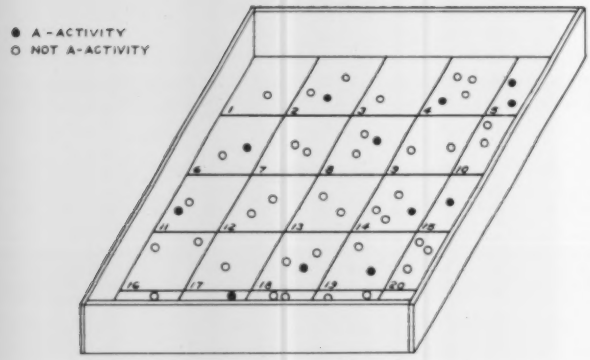

FIG. 3. A Model Representation of the Distribution of People in a Plant at this Instant in Time Engaged in *A* or Not-*A* Activity.

With no more statistics than that shown in Eq. 3., one would find that by repeating the foregoing procedure an appropriate number of times the value of the fraction f, would approach the true fraction of colored beads in the original bowl. This fraction would represent the amount of time the people under study in this theoretical situation spend traveling.

Estimates of precision will be discussed later.

APPLICATION OF CONCEPTUAL MODEL TO ACTUAL SITUATION

Reducing the model described to the actual situation requires the following:

1. Information on the average physical distribution of people in the plant being studied. Areas where people may be concentrated, fixed and stable, or areas very sparsely populated may be separated out for individual study, or designed into the study.

2. On an actual map of the plant, approximate the average distribution of the people.

3. Draw a series of variable sized grids (called greds hereafter as explained) over the plant-people map including operating areas (shops, processing areas, laboratories, etc.) and travel areas (passageways, roads, etc.) in such as manner that each gred contains on the average n people (in the example here, $n = 2$). The geographical size of the greds will vary but their population should tend to be uniform. The term gred has been used to describe these geographically variable sized grids having (ideally) uniform populations. The population determines the geographical size.

4. Number the greds in serial or serpentine order. Figure 4 illustrates a typical situation at a particular instant in time in a plant.

MAKING OBSERVATIONS

The observer needs the following information and tools. He must know the plant and the people and have a map of the plant with the gred areas shown and described in additional detail if necessary. The observer must also have a list of well defined mutually exclusive categories into which he can classify his observations (7). In additions, he needs a supply of random numbers (8).

The observer then proceeds to make his study in a manner similar to that described for the theoretical model. He takes the first random number, e.g. 22, proceeds to area designated as 22 on the map and observes the total number of workers in the gred area (this may be none, one, two or more. On the average it will be n.) The observer identifies what the people are doing, records this information, then proceeds to the next random gred. In a relatively large study an observer will usually work a full day continually observing. In smaller studies he may randomly allocate his time and only observe for part of a day. Care needs to be exercised in part time observing to prevent bias from being introduced.

GREDS THEORY

In the applied model described, the term gred was used to describe the variable sized grids used, to distinguish them from grids, which in normal usage implies uniform physical dimensions.

A descriptive summary of this technique has been referred to as Theory of GREDS. (GREDS—the use of Greds for Ratio Estimates of Delays by Sampling.)

RATIO METHOD—THE RATIO ESTIMATE

In sampling to determine a fraction, such as the direct work effort to total work effort, the ratio estimate meets the requirements outlined in the introduction, conforms to the physical or actual model outlined and is superior to the binomial model in our applications and experience.

The total population of people being sampled, involves time and geography. The sample units occur as gred populations. If one had 50 people and 25 greds there would be an average gred population of 2 ($\bar{x} = 2$).

In the gred, two things are measured and these two things are associated: the first is the gred population itself which may be designated as x_i; and the second is the activity of the population in the gred, recorded as y_i.

The formula for estimating the fraction or proportion of y_i activity of the x_i population is:

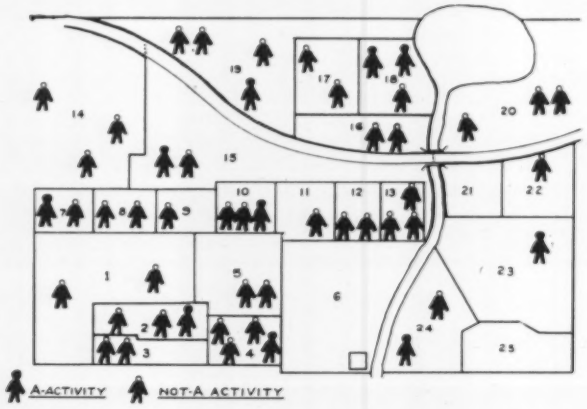

FIG. 4. An Illustrative Map of a Plant Showing a Distribution of Personnel in Greds at an Instant of Time Engaged in Either *A* or Not-*A* Activity.

$$f = \frac{\sum_{1}^{m} y_i}{\sum_{1}^{m} x_i} \qquad \text{Eq. 5.}$$

The terms are defined as follows:

x_i = the total number of people observed in the ith gred.

y_i = the number of people in the ith gred engaged in A activity. The remainder of people in the gred are engaged in "Not-A" activity.

m = the sample size, or the total number of gred units observed.

Separate ratio estimates are obtained for each activity of interest in the population. In each case the total x will be the same.

THE VARIANCE OF THE RATIO ESTIMATE

The estimate of the variance of f, is given by:

$$\text{Variance } f = \frac{1}{m(m-1)\bar{x}^2}\left[\sum y_i^2 + f^2 \sum x_i^2 - 2f \sum y_i x_i\right] \qquad \text{Eq. 6.}$$

m = sample size, number of gred units observed.
x_i = total number in ith gred.
y_i = number in ith gred engaged in A activity.
f = defined in Eq. 5.
$\bar{x}$ = average gred population, $\sum x_i/m$.
$\sum y_i^2$ = sum of the squares of y_i.
$\sum x_i^2$ = sum of the squares of x_i.
$\sum y_i x_i$ = sum of the cross products.

Table 1 gives an example of numbers substituted in this formula. The standard deviation of f is the square root of variance f:

$$s_f = \sqrt{\text{var} f}$$

In large samples the distribution of the Ratio Estimate approaches the normal distribution and one may use the standard deviation s_f together with tables of the normal distribution function to establish uncertainty limits around f; for example, $f \pm 3\ s_f$ will give 3-sigma confidence limits.

THE VARIANCE OF THE RATIO ESTIMATE—CALCULATION OF SAMPLE SIZE (m)

An equivalent formula, which under certain circumstances, is very useful, particularly for estimating the sample size m, is the following. Note that this formula is in terms of coefficients of variation. A coefficient of variation gives the relative variation. This relative variation is the standard deviation expressed as a fraction or percent of the estimate being made.

For example, if we had a standard deviation of 0.05 and an estimate of $f = .50$, the coefficient of variation or relative variation of f would be

$$C_f = \frac{S_f}{f} = \frac{0.05}{.50} = 0.10$$

or expressed as a percent it would be 10%.

$$C_f^2 \doteq \frac{1}{m}\left[C_y^2 + C_x^2 - 2rC_xC_y\right] \qquad \text{Eq. 7.}$$

TABLE 1

*Some Illustrative Results for Calculating the Variance of f for the Whole Population and for a Subpopulation**

Order of Obs.	Gred No.	Total Gred Population x_i	A Activity of Population y_i	x_i^2	y_i^2	x_iy_i	Subpopulation of Gred x_{is}	A Activity of Subpopulation y_{is}	x_{is}^2	y_{is}^2	$x_{is}y_{is}$
1	12	2	1	4	1	2	1	0	1	0	0
2	19	1	0	1	0	0	0	0	0	0	0
3	20	3	1	9	1	3	1	1	1	1	1
4	16	0	0	0	0	0	0	0	0	0	0
5	25	2	1	4	1	2	2	1	4	1	2
6	5	2	1	4	1	2	1	1	1	1	1
7	8	3	2	9	4	6	2	1	4	1	2
8	3	3	2	9	4	6	1	0	1	0	0
Totals	—	16	8	40	12	21	8	4	12	4	6

* Illustrative only—one would not calculate results on so few data:

$$\text{Fraction of } A \text{ activity of whole population } f = \frac{\sum y_i}{\sum x_i} = \frac{8}{16} = 0.5$$

$$\text{Fraction of } A \text{ activity of sub-population e.g., (one craft)} = f_s = \frac{\sum y_{is}}{\sum x_{is}} = \frac{4}{8} = 0.5$$

Variances calculated by Eq. 6. substituting appropriate values summarized above.

$$\text{Variance of } f \text{ for the whole population} = \frac{1}{8(7)(4)}\left[12 + .25(40) - 2(.5)(21)\right] = 0.0045$$

$$\text{Variance of } f_s \text{ for the sub-population} = \frac{1}{8(7)(1)}\left[4 + .25(12) - 2(.5)(6)\right] = 0.018$$

where

C_f = coefficient of variation of $f = s_f/f$
C_x = coefficient of variation of $x = s_x/\bar{x}$
C_y = coefficient of variation of $y = s_y/\bar{y}$
r = correlation coefficient between the pairs of x and y

$$= \frac{\frac{1}{m}\sum_{1}^{m}(x_i - \bar{x})(y_i - \bar{y})}{s_x s_y}$$

$$= \frac{m\sum xy - (\sum x)(\sum y)}{\sqrt{[m\sum x^2 - (\sum x)^2][m\sum y^2 - (\sum y)^2]}}$$

The latter equivalent formula for r is useful for calculations since most of the terms would already have been totaled.

In calculating the sample size for the binomial, the usual practice is to approximate the anticipated proportion, determine the degree of precision or the standard error required and solve Eq. 2. for n.

In using the Ratio Estimate approach, one uses essentially the same process. Approximate the coefficients of variation and correlations expected, determine the degree of precision or standard error required and solve Eq. 7. for m. Approximations can be made on the basis of a preliminary pilot study.

Description and theory of Ratio Estimates are given in (2), (4), (6) where many other equivalent formulas for calculations are listed.

VARIANCE OF THE RATIO ESTIMATE—USE OF RANGE FOR ESTIMATING COEFFICIENT OF VARIATION f

The equations given define the exact mathematical model behind this technique. In actual practice a good estimate of precision can be obtained through the use of the range.

This extremely simple method of evaluating the precision of the ratio estimates was suggested to me by Dr. W. Edwards Deming in a private communication. The theory is elaborated in considerable detail in his paper "On Simplifications Of Sampling Design Through Replication With Equal Probabilities And Without Stages" (5).

The suggested technique is to replicate the design with 4 interpenetrating sub-samples, calculate the four values of f for each of the sub-samples, namely f_1, f_2, f_3, f_4, then estimate the standard deviation by the following formula:

$$s_f \doteq \frac{R}{4} \qquad \text{Eq. 8.}$$

where $R = f$ max. $- f$ min. The factor 4 is the product of the Tippett constant $d_2 = 2.06$ for a sample of size 4, multiplied by

$$\sqrt{4}.$$

TABLE 2

*Some Illustrative Results for Calculating the Coefficient of Variation of f from 4 Interpenetrating Sub-Samples**

	Sub-Sample 1		Sub-Sample 2		Sub-Sample 3		Sub-Sample 4	
	x	y	x	y	x	y	x	y
	1	0	1	0	2	1	1	0
	2	1	1	1	2	1	2	0
	1	1	3	2	0	0	1	0
	0	0	0	0	1	1	0	0
	1	1	2	2	2	1	1	1
	2	0	1	1	4	2	1	1
	1	1	0	0	1	0	2	2
	2	0	3	1	0	0	1	1
Totals	10	4	11	7	12	6	9	5

* Illustrative only—one would not calculate results on so few data.

The coefficient of variation would be given by

$$\hat{C}_f = R/4f.$$

The interpenetrating sub-samples may be obtained by assigning the observation obtained from the first random number to sub-sample 1, the second random number to sub-sample 2, the third to sub-sample 3, the fourth to sub-sample 4, the fifth to sub-sample 1 again, the sixth for sub-sample 2, and so on.

In Table 2 a set of data is given to illustrate the application of this formula. In actual computations good agreement between the more formal calculations and the simplified estimate given in Eq. 8. was achieved. The estimate of a coefficient of variation from the four interpenetrating sub-samples is usually sufficiently precise for most practical uses of the data.

From Table 2, values of:

$$f_1 = \frac{4}{10} = 0.400$$

$$f_2 = \frac{7}{11} = 0.637$$

$$f_3 = \frac{6}{12} = 0.500$$

$$f_4 = \frac{5}{9} = 0.555$$

$$f = \frac{1}{4}(f_1 + f_2 + f_3 + f_4) = 0.52$$

Substituting in Eq. 8. for an estimate of the standard deviation gives:

$$s_f \doteq \frac{R}{4} = \frac{0.237}{4} = 0.059$$

The coefficient of variation is

$$\hat{C}_f \doteq \frac{R}{4f} \doteq \frac{0.237}{4(0.52)} \doteq .11 \text{ or } 11\%.$$

In this case the same result for the standard deviation

or the coefficient of variation of f is obtained by the use of either Eq. 6. or Eq. 7.

DISCUSSION OF THE TECHNIQUE

One advantage of the use of these formulas, which is not immediately obvious because of the greater complexity of the formulas, is the possibility of greater precision. For example, if the coefficient of variation of the denominator x of the ratio f is small compared to the coefficient of variation of the numerator y of the ratio being estimated, some gain results using the ratio estimate, as compared to the binomial estimate, even with low correlation (6). The basic design recommended in this study tends to give a correlation between x and y, since y cannot be greater than x by definition.

If one plotted x against a y characteristic, the regression line would tend to have a zero intercept, the variability of the points y_i generally increase as x_i increases, and the slope of the line tends to be close to the Ratio Estimate. One will have an equation of the type $y = a + bx$.

Uniform gred populations are required for best precision. This is another way of saying the coefficient of variation of the denominator should be as small as possible. It is worthwhile to spend time in preliminary planning work toward this objective. However, if this is not achieved in practice, the estimates are still valid and the final conclusions will be valid, but precision will not be as good as with uniform populations.

Theoretically, there is a slight mathematical bias in the ratio estimate, a discussion of which is beyond the scope of this article. However, with the design outlined here and sample sizes of over several hundred observations, this bias is so slight as to be negligible and it would be less than the standard error. For a fuller discussion, references (2), (4), (5) and (6) are recommended.

A very significant factor in the use of this approach is that it takes account of the effects of people working together. In the binomial, with the route system, if two people are working together and both are observed, they are considered as being independent by the theory, but may not be in fact.

GRED POPULATIONS

Some "rules of thumb" and suggestions for gred populations:

1. Minimize, if possible, the number of empty greds. Empty greds do not invalidate the data, and may contribute useful information, but not necessarily optimum information.
2. The population per gred should not be too large from the practical standpoint since the observer must a. count the total number of people and b. observe their respective states of activity without introducing bias by his presence. Occasional greds may have large populations, but on the average, more than five is not recommended.
3. The population per gred should be as uniform as practical. This means that it is worthwhile to spend time in establishing the greds to be used before the actual study is begun.

THE ANALYSIS OF SUB-CLASS VARIANCE

In studying a population to determine its characteristics, frequently it is desirable to summarize the characteristics of a sub-population. (Here a sub-population means a logical subdivision of the whole population being studied. It might be a section within a department.) In sampling a work force, such as a maintenance department, one may wish to determine the activity of one of the crafts in a section of the department and make estimates of standard deviations of the activity categories.

The fraction of A activity of the sub-population is obtained by summarizing the x and y values for the sub-population and substituting in Eq. 5. The variance is calculated by substituting the appropriate summary values in Eq. 6. The value of m to be used is the total m, not the m for the sub-population. The value of $\bar{x}_{is}^2$ for the sub-population is the sub-population total, $\sum x_{is}$ divided by the total of m greds.

A set of illustrative data along with prototype calculations are shown in Table 1.

Eq. 8. may also be used for the estimates.

HOW MANY OBSERVATIONS?

The economic question of how many observations to take is one that is usually left to the discretion of the statistician supervising the computations. On the problem of the precision required of the study, many work sampling advocates recommend 95% confidence limits and someone selects a sample size to give the appropriate plus or minus limits.

While the technical aspect of sample size is logically the province of those trained in this work, it is useful to put an economic price tag on the values to give the non-technical manager precision in terms that are most meaningful to a businessman. One criterion we have used to evaluate the precision required is to convert the percentages and their respective "errors" to dollars and then determine whether this precision is adequate for making the practical business decisions. For example, suppose one had two categories showing the following results:

A is 20% ± 1% (Relative error of 5%)
B is 1% ± 1% (Relative error of 100%).

If now for example 1% = $10,000 we have:

A is $200,000 ± $10,000
B is $ 10,000 ± $10,000.

In looking for improvements in the $200,000 category, perhaps we can see that by making a major change in organization, communications, or a control system at a cost of $10,000 it appears probable that the $200,000 can be reduced by $60,000. Now in terms of the new investment costs and the possible "error" of the difference between the original A value and the reduced A level, there will be a significant gain possible.

On the $10,000 category, the potential may range from nil to $20,000. Is it worthwhile attempting to reduce this? Can we afford additional study to get a more precise estimate or can we afford capital investment to achieve a reduction if the value is actually $10,000?

Using the Greds approach for the technical aspect and a dollar analysis of potential along the lines indicated above, our experience has indicated sample sizes (number of greds observed) range from about 1,000 to 4,000.

One should include the cost of the study, including the planning phase, the observation phase, the summarization step, and the development of alternatives. Work sampling is not recommended unless it can be reasonably demonstrated that there will be a payoff.

WORKER OUT OF THE AREA

Under the plan outlined (application of conceptual model to actual situation), it is clear that if a person has reported for work and is in the plant, he must by definition, be in one of the Greds. The problem of a person being missing or out of an area is impossible unless the person is not at work or away from the plant on some assignment.

If a study is being made of only a part of a plant then it becomes necessary to define the area in which the people will be located and to account for people out of the designated areas. A small known percentage of out of area people creates no particular problem and the data can be adjusted accordingly.

By definition, the theoretical population per gred is a known value. For example, 50 people in 25 greds gives an average of 2.0 people per gred. Deviations from this value can, of course, be evaluated and if the number is not within the range of the expected value then something has gone wrong. This is an excellent internal check of validity.

APPLICATIONS

The technique outlined has many applications in industry and can be very useful if applied to the right problem areas and if the results are evaluated and utilized according to good management practices.

This article has not covered the management aspects of determining where to use the technique, defining the problem area to be studied, selling the technique, management evaluation of the results, or determination of alternative courses of action suggested by the data and recommendations for action. Any one of these points can be more important than the technique itself and be the reason for success or failure of the application of the theory.

CONCLUSIONS

A new technique for work sampling has been presented which guarantees randomness by the use of random numbers and uses the more general formula of the Ratio Estimate instead of the classical binomial model.

The application of this new model and technique, which for convenience has been called the GREDS theory:

1. Allows for more flexibility and simplicity in the operational aspects of work sampling.
2. Is claimed to give either greater precision for a given cost or greater validity in the final results.
3. Provides a mathematical model and technique which are consistent and eliminates the necessity for deviating from a model because of practical considerations.
4. Eliminates the need to find specific people in the population under study.
5. Eliminates the problem of missing people in a mobile work force engaged in activities that require travel, changing work locations and variable tasks.
6. Is based on a somewhat more complicated model, but an extremely simple method for estimating sampling variation using the range is given.

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Application of Dynamic Programming to a Class of Problems in Inventory Control*

by ARJAN BHATIA and ANAND GARG

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A REQUIREMENT schedule in the form of number of units required at the beginning of each of the next n time periods is given. This is required in order to determine a buying (or production) schedule such that the sum of inventory holding costs and fixed costs associated with each shipment (or production run) is minimized.

A general dynamic programming approach is presented. Inventory control problems, with known but variable requirements at discrete points of time and having an objective function with a fixed and a variable portion, can be efficiently handled by the dynamic programming technique. The method is readily applicable to the specific problem presented and offers substantial savings in computation.

Various models have been formulated by a number of writers on the general problem in inventory control. Except for the simplest case of uniform known demand over the entire time period, most of these models are designed to determine the reorder quantity for a single period. The effect of the current order on the policy for subsequent periods is usually ignored. A relatively simple method for determining optimum ordering policy for a number of periods is presented in this article.

PROBLEM FORMULATION

To present the concepts, we will treat the case of known requirements. Let

r_i = requirements for ith period, $i = 1, 2, \cdots, n$.

X_i = quantity scheduled to be delivered at the beginning of ith period, $i = 1, 2, \cdots, n$.

Cost considerations:

S = fixed cost associated with each delivery.

λ = inventory holding cost per period per unit.

The problem is to find non-negative X_i's, such that

$$\sum_{i=1}^{j} X_i \geq \sum_{i=1}^{j} r_i \quad \text{for all } j = 1, 2, \cdots, n-1 \qquad \text{Eq. 1.}$$

$$\sum_{i=1}^{n} X_i = \sum_{i=1}^{n} r_i \qquad \text{Eq. 2.}$$

and the cost function 2 is minimized where

Z = Inventory holding costs + Delivery costs

$$= \lambda \left\{ \frac{X_1 + [X_1 - r_1]}{2} + \frac{[X_1 - r_1 + X_2] + [X_1 + X_2 - r_1 - r_2]}{2} + \cdots \right.$$

$$\left. + \frac{[X_1 + X_2 + \cdots + X_n] - [r_1 + r_2 + \cdots + r_{(n-1)}] + [X_1 + X_2 \cdots + X_n] - [r_1 + r_2 + \cdots + r_n]}{2} \right\}$$

$$+ S[\text{Total number of deliveries}]$$

$$= \lambda \left[(X_1 - r_1) + (X_1 + X_2) - (r_1 + r_2) + \cdots + (X_1 + X_2 + \cdots X_n) - (r_1 + r_2 + \cdots + r_n) \right.$$

$$\left. + \frac{(r_1 + r_2 + \cdots + r_n)}{2} \right] + S \sum_{i=1}^{n} g_i$$

where

$$g_i = 1 \quad \text{for} \quad X_i > 0$$

$$g_i = 0 \quad \text{for} \quad X_i = 0$$

$$Z = \lambda \left[\sum_{j=1}^{n} \left(\sum_{i=1}^{j} X_i - \sum_{i=1}^{j} r_i \right) + \frac{1}{2} \sum_{i=1}^{n} r_i \right] + S \sum_{i=1}^{n} g_i \qquad \text{Eq. 3.}$$

where

$$g_i = 1 \quad \text{for} \quad X_i > 0$$

$$g_i = 0 \quad \text{for} \quad X_i = 0$$

* It has come to the authors' attention that this article is very similar to the approach taken by Wagner and Whitin in their article, "Dynamic Version of the Economic Lot Size Model," published in *Management Science*, October, 1958. At the time of developing this approach, the authors were unaware of the work of Wagner and Whitin in this area.

The foregoing formulation is based on the following considerations:

1. Inventory in each period is depleted at a uniform rate.
2. There is no inventory at the beginning of the first or at the end of the last period.
3. A single order specifying the delivery schedule is placed at the beginning of the first period. (There is no point in issuing more than one purchase order.)
4. The unit price is based on the total quantity ordered and is independent of the delivery schedule. (If the unit price is known to be dependent on the delivery schedule in a definite way, the cost function can be suitably modified without changing its basic structure.)
5. Since the requirements are known and are fully met as specified by Eq. 1. and Eq. 2., no shortages and surpluses will occur.

PRESENT METHODS OF SOLUTION

Two methods are presently available to handle the problem. The first method assumes that a constant quantity is delivered each time, while the second method consists in finding the costs associated with all possible combinations of $1, 2, \cdots, n$ deliveries and to select the schedule giving the least cost. The first method does not yield an optimum solution and the second method becomes quite cumbersome as the number of periods increases. The total number of computations required is 2^{n-1} where n is the number of periods.

Under the assumptions stated earlier, it is clear that no requirements would be split; that is, each $r_i (i = 1, 2, \cdots n)$ will be obtained in its entirety. Further, if a shipment is obtained at time T, it should be able to cover the requirements for the next 1 or 2 or $3 \cdots$ or $n-T$ periods. In any period, we have the choice of getting a shipment of goods, or not getting anything by getting the required quantity for the period in the earlier shipment, except for the first period when we have to get a minimum shipment of r_1. The total number of such combinations is 2^{n-1}, where n is the number of periods. For example, consider the case of 3 periods with requirements r_1, r_2 and r_3 for the first, second and third periods, respectively. The feasible solutions are:

No.	Quantity Shipped in Period		
	1	2	3
1	$r_1+r_2+r_3$	—	—
2	r_1+r_2	—	r_3
3	r_1	r_2+r_3	—
	r_1	r_2	r_3

For $n = 32$, the number of computations is 10^9, approximately. Even with the help of a large-scale digital computer, for large values of n, the problem can get out of hand.

A much more efficient method employing the dynamic programming technique is presented.

DYNAMIC PROGRAMMING APPROACH

The dynamic programming approach is based on the following principle: An optimal decision policy has the property that, whatever the initial decision is, the remaining decisions must constitute an optimal policy with respect to the state resulting from the initial decision.

Let

$f(t)$ = minimum cost for satisfying requirements up to time t.

$R(T, t)$ = cost of a schedule satisfying requirements up to time t, such that last nonzero delivery was made at time T with all the previous deliveries made in an optimal fashion to meet requirements up to time $T-1$.

$I(t_1, t_2)$ = inventory holding cost from time t_1 to time t_2.

S = fixed cost associated with each delivery.

The dynamic programming functional equations for the system may be written as

$$R(T, t) = S + I(T, t) + f(T-1); \qquad 1 \leq T \leq t, t = 1, \cdots, n \quad \text{Eq. 4.}$$

and

$$f(t) = \min_{1 \leq T \leq t} [S + I(T, t) + f(T-1)], \qquad t = 1, \cdots, n \quad \text{Eq. 5.}$$

with

$$f(0) = 0, \qquad I(T, T) = 0.$$

We start computation at $t = 1$ and proceed until $t = n$. At every stage, we have not only the minimum cost, but also the minimum cost schedule for satisfying requirements up to that stage.

Let

$B(t)$ = the schedule with a minimum cost for satisfying requirements up to time t
$= X_1, X_2, \cdots, X_t \qquad t = 1, \cdots, n$

$G(T, t)$ = a schedule for satisfying requirements up to time t, such that the last non-zero delivery was made at time T with all the previous deliveries made in an optimal fashion to meet requirements up to time $T-1$.

$$G(T, t) = B(T-1), X_T, X_{T+1}, \cdots, X_t \quad \text{Eq. 6.}$$

where

$$X_T = \sum_{i=T}^{t} r_i, X_{T+1} = 0, \cdots, X_t = 0.$$

for $1 \leq T \leq t, t = 1, 2, \cdots, n$.

Let t^* be that value of T which minimizes

$$[S + I(T, t) + f(T-1)];$$

that is,

$$S + I(t^*, t) + f(t^* - 1) = \min_{1 \leq T \leq t} [S + I(T, t) + f(T-1)] \qquad t = 1, \cdots, n \quad \text{Eq. 7.}$$

Then the schedule with a minimum cost, $B(T)$ may be written as

TABLE 1

Comparison of Two Methods

A. Trying all Combinations
B. Dynamic Programming Approach

No. of Periods	Max. No. of Computations		Time on IBM 704 Computer*	
	Method A	Method B	Method A	Method B
10	512	55	.17 Mins.	1.1 Secs.
15	16,384	120	5.34 Mins.	2.4 Secs.
20	504,000	210	171 Mins.	4.2 Secs.
25	1.6×10^{8}	325	3.8 Days.	6.5 Secs.
30	$.5\times10^{9}$ appr.	465	122 Days.	9.3 Secs.
35	1.6×10^{10} appr.	630	10.8 Yrs.	12.6 Secs.

* Time per computation = 0.02 secs. approximately.

$$B(t) = G(t^*, t) = B(t^* - 1),$$

$$X_{t^*} = \sum_{i=t^*}^{t} r_i, X_{t^*+1} = 0, \cdots, X_t = 0$$

$$t = 1, \cdots, n \quad \text{Eq. 8.}$$

where t^* is obtained from Eq. 7.

COMPARISON OF DYNAMIC PROGRAMMING APPROACH WITH PRESENT METHODS

If n is the number of periods under consideration, the number of computations under the above procedure is given by

$$\text{Number of computations} = \frac{n(n+1)}{2} \quad \text{Eq. 9.}$$

The two methods are compared in Table 1.

These results indicate the tremendous savings which are possible by using the dynamic programming method in solving the stated problem.

AN ILLUSTRATIVE EXAMPLE

The dynamic programming approach will be illustrated by a simple example. The example presented below is purely illustrative and is restricted to only 5 periods.

Data

REQUIREMENT SCHEDULE

Time	Requirements (No. of Units)
1	100
2	200
3	300
4	250
5	150
Total	1,000

λ = \$.02 per unit per period
S = \$15 per delivery

Computations

From Eq. 6. we note that

$$X_T = \sum_{i=T}^{t} r_i, \qquad X_{T+1} = X_{T+2} = \cdots = X_t = 0.$$

Hence, the variable inventory holding cost, $I(T, t)$ is given by:

$$\begin{aligned} I(T,t) &= \lambda[(X_T - r_T) + (X_T - r_T - r_{T+1}) \\ &\quad + (X_T - r_T - r_{T+1} - r_{T+2}) + \cdots \\ &\quad + (X_T - r_T - r_{T+1} - \cdots - r_t)] \\ &= \lambda\left[(T - t + 1)X_T - \sum_{j=T}^{t}\sum_{i=T}^{j} r_i\right] \quad \text{Eq. 10.} \end{aligned}$$

The results of the computations are shown in Table 2 and are self-explanatory. The optimum schedule $B(5)$ is

TABLE 2

No. of Periods Considered	Period at Which Last Non-Zero Delivery was Made	Delivery Schedule—Number of Units $G(T,t)$					Variable Cost of the Schedule				Min. Cost Schedule $B(t)$	Cost of Min. Cost Schedule $f(t)$
							$f(T-1)$	$I(T,t)$	S	$R(t)$		
t	T	x_1	x_2	x_3	x_4	x_5	\$	\$	\$	\$		\$
1	1	100					0	0	15	15	←	15
2	1	300	—				0	4	15	19	←	19
	2	100	200				15	0	15	30		
3	1	600	—	—			0	16	15	31	←	31
	2	100	500	—			15	6	15	36		
	3	300*	—*	300			19	—	15	34		
4	1	850	—	—	—		0	31	15	46		
	2	100	750	—	—		15	16	15	46		
	3	300*	—*	550	—		19	5	15	39	←	39
	4	600†	—†	—†	250		31	—	15	46		
5	1	1000	—	—	—	—	0	43	15	58		
	2	100	900	—	—	—	15	25	15	55		
	3	300*	—*	700	—	—	19	11	15	45	←	55
	4	600†	—†	—†	400	—	31	3	15	49		
	5	300††	—††	550††	—††	150	39	—	15	54		

* Optimum schedule for the first two periods.
† Optimum schedule for the first three periods.
†† Optimum schedule for the first four periods.
← Indicates the minimum cost schedule.

$$X_1 = 300, \quad X_2 = 0, \quad X_3 = 700, \quad X_4 = X_5 = 0$$

giving the minimum variable cost of $45.

While the foregoing hand computations appear rather cumbersome, they represent substantial savings over the existing methods of computing costs for all possible combinations. This method has been programmed for an IBM-704 computer of the Boeing Airplane Company.

REQUIREMENTS GIVEN IN THE FORM OF CONTINUOUS FUNCTION

The foregoing procedure is restricted to a discrete case because in practical problems the data are provided in such form. Great ease in computation can be achieved whenever the requirements can be approximated by a continuous function. The procedure is similar to the one presented and a suitable algorithm can be formulated for most continuous functions.

CONCLUSIONS

A general dynamic programming approach to inventory control problems of known but variable demands is presented. The method developed here is quite general, and does not make any restricting assumption with regard to the manner in which demands arise, and can be easily programmed for any electronic computer.

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Report on the Second System Simulation Symposium

by **JOHN W. PORTER**

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THE Second System Simulation Symposium (3) was held at Northwestern University on February 3-4, 1959. The sponsoring societies, the American Institute of Industrial Engineers, the Institute of Management Sciences, and the Operations Research Society of America, also sponsored the first symposium (1) (2) held in May, 1957. The first symposium generated interest in simulation as a method of analysis and training. The second symposium was conducted primarily as a workshop to explore the problems of understanding and effectively utilizing the concepts.

Sixty-four attendees from business, consulting, and academic fields had a common interest in utilizing simulation on a project. The first morning was spent in briefly reviewing the field of activity and setting the stage for the workshop sessions. The attendees were then assigned to six workshop groups to discuss the problems in effectively planning, organizing and conducting a simulation project with a view toward drawing some general principles and evaluation of the approach. These small groups met during the afternoon of the first day and the morning of the second day. Group leaders summarized the findings and comments of their respective workshops before the entire session on noon of the second day. A discussion of Industrial Dynamics on the afternoon of the second day was followed by concluding remarks from the symposium chairman, Mr. Warren Alberts of United Air Lines.

Following a brief welcome by Dean H. B. Gotaas of the Technological Institute of Northwestern University, Chairman Alberts introduced the two-day program and arrangements.

KEYNOTE SPEAKER, RICHARD BELLMAN

The keynote speaker, Mr. Richard Ballman of the Rand Corporation, stimulated the group with some pertinent, overdue remarks regarding the entire field of scientific endeavor and the area of model making and simulation in particular. After exposing that the construction and type of model is determined more by the scientific training and philosophy of the model maker than anything else, he proceeded to discuss the problems in finding people with the basic requirements for research in the area of simulation. The failure of the university to produce properly trained professional people was effectively summarized by the statement, "The emphasis upon facts rather than ideas, upon subjects rather than problems, effectively rules out the systems approach so essential in the study of any scientific situation." Mr. Bellman urged the universities to develop "a proper spirit of humility" in their scientific training, and pointed to the field of mathematics where improper deterministic concepts had overshadowed the development of this spirit. He suggested that an emphasis on the life sciences could correct in part, or in whole, the misconception that the more qualitative and human subjects of the social sciences are easier than quantitative subjects such as mathematics.

Following the keynote address, each of the sponsoring societies were represented by speakers.

AIIE REPRESENTATIVE, DONALD MALCOLM

Mr. Donald Malcolm, representing the AIIE, surveyed the use of simulation in management analysis. Examples were given where simulation projects had been used for training, system design and evaluation, and system research and planning. The use of computers in the management process as a data-processing tool, a problem-solving tool, and a controlling device were summarized. In discussing the purposes in using simulation, a distinction was made between competitive simulation, where the situation under study involves the interactions of individuals, companies, or countries competing toward common interrelated goals; and system simulation, where the system, be it man or organization, is being studied in a changing environment or with changed system parameters. Problems encountered in the use of simulation were listed. The future outlook for simulation both for a better understanding of process and as a possible tool for administering policy was considered in the vein of the impact of computer models on the freeing of decision makers' time for understanding model limitations and seacning imaginatively for beneficial innovation.

TIMS REPRESENTATIVE, DAVID HERTZ

Mr. David Hertz, representing TIMS, spoke on simulation for problem solving. The point was made that simulation is not confined to computer simulation. Computer use is strictly a matter of economics, and many specific solutions are manually calculated. The problem solving aspects of simulation were divided into three categories.

1. Problem Simulation—where the simulation model itself provides sufficient insights into processes under consideration to lead to adequate or better solutions to the decision problems.
2. Decision Rule Test Simulation—where there are one or more solutions to the decision problems which it is desired to test in the face of a simulated reality.
3. Parametric Simulation—where the problem is to determine the setting of parameters or variables that give the most desirable operating answers, or to check the sensitivity of solutions to changes in various parameters of the problem variables.

Examples of each of the foregoing types of simulation were given, and Mr. Hertz concluded with the thought that simulation is a wonderful tool in business problem solving if used with imagination, competence, confidence, and courage.

ORSA REPRESENTATIVE, THOMAS CAYWOOD

The speaker representing ORSA was Mr. Thomas Caywood, who discussed simulation for business training. The history of management games was presented, along with a brief description of the general format of the various current games. It was admitted that management games are fun to play and offer an interesting way of showing the effects of certain assumed laws of industrial operations. However, Mr. Caywood issued a challenge to people working on management games as to whether they have proved to be more than this. The actual benefits obtained from management games in studying the learning process, decision making, and organization structure were questioned along with the value of such games as training aids. Whether management games are more useful than other games as a means of evaluating and selecting leaders was also questioned. Mr. Caywood concluded with a desire to see the activity in management games move a bit away from the emphasis of a parlor game and more into the research fields. A resulting benefit to the science of management was foreseen from such a move.

FIRST WORKSHOP GROUP

The first workshop group conducted by Mr. Burton Dean of Case Institute of Technology and Mr. Norman Jennings of the Port of New York Authority reached general conclusions in the following six areas:

1. Introduction of simulation within an organization.
2. Organization of simulation effort.
3. Staffing of simulator team.
4. Operation of simulation activity.
5. Costs and returns from simulation.
6. Format of future meetings of the symposium.

The group concluded that a successful simulation effort requires the development of an atmosphere that is inventive and creative. It was considered most essential that a high degree of communication exist between the simulator team and the consumers of the simulation effort.

SECOND WORKSHOP GROUP

The second workshop group chaired by Mr. Clifford Craft of Peat, Marwick, Mitchell and Company was concerned with management games, and the discussion centered around the following seven questions:

1. What management games are available?
2. What "gimmicks" are helpful in the design of a management game?
3. What kinds of people can profitably play management games?
4. How can you evaluate and compare management games?
5. How can you introduce qualitative factors into management game situations?
6. What can management games be used for?
7. What direction should management game design take?

The group concluded that after much experience has been gained in the field, no doubt certain practical uses of management games in personnel testing will emerge.

THIRD WORKSHOP GROUP

The third workshop group chaired by Mr. Benjamin Bryton of General Electric Company was concerned with problem solving, and the group set up a purchasing problem suggested by one of the members. All individuals in the group also actually solved a simple theoretical inventory problem, which was followed by a discussion and comparison of results. The following conclusions were developed:

1. Simulation is a very broad tool, applicable to many cases.
2. It is a relatively simple tool, and easy to do and understand.
3. Useful results can be obtained quickly and often with relatively little data.
4. It is a very powerful communication and liaison device between researchers and operations people.

FOURTH WORKSHOP GROUP

The fourth workshop group chaired by Mr. Robert Rohr of Eastman Kodak Company and Mr. William Sutherland of Johns Hopkins University was also concerned with problem solving. The group discussed the characteristics of simulation used for problem solving. The need for conceptual ability by persons doing simulation work was considered important, and the problem of selecting people with this ability was discussed. The group brought out two cautions with respect to simulation.

1. There is some danger on the part of people who are not completely familiar with simulation to expect too many answers from simulation. They have some tendency to ask for answers for which there is no suitable input available.
2. Simulation is only one of the tools that is available in the workshop. To a degree, simulation should be reserved for those problems which are not amenable to other methods of analysis. However, it was pointed out that simulation is a potent means of communication, and it is generally easier to explain systems and results through simulation models than through mathematical models.

FIFTH WORKSHOP GROUP

The fifth workshop group was concerned with problem solving and business training and was conducted by Mr. Andrew Vazsonyi of Thompson Ramo-Wooldridge Corporation. The problems in selecting a problem for simulation were discussed along with the scope of simulation. The group concluded that simulation was merely a tool of system design or operations research and its use therefore, should be based on the needs of the problem. Agreement was reached that consultants can be useful in providing technical assistance to a simulation project. Consultants are also useful to check the thinking of a project team and can aid in training people. However, it was felt that a simulation job should not be contracted out to a consultant, and the consultant should not do the complete job if the company is to receive maximum benefit from simulation efforts.

SIXTH WORKSHOP GROUP

Mr. Strother Walker of the Operations Research Office conducted the discussion of the sixth workshop group on problem solving. In evaluating the simulation method as to approach and results, questions regarding validity, reliability, and reproducibility were raised by members of the group with simulation experience. The pros and cons of the team approach on simulation problems were discussed with regard to size of the team and talents required. The groups agreed that development of a new class of specialists in simulation is not wanted; and that no special talent or background is required for successful employment of computer simulation, beyond straightforward ability in one of the many relevant technical or scientific fields. The group also spent some time exchanging knowledge and points of technique derived from actual experience with computer simulations. This led to group recommendations for furthering the exchange of information on simulation experiences and techniques.

INDUSTRIAL DYNAMICS

During the evening following the first day's sessions, attendees were asked to read Mr. Jay Forrester's paper on Industrial Dynamics. During the afternoon of the second day, Mr. Forrester answered questions regarding Industrial Dynamics. Most of the questions dealt with the impact of the industrial dynamics concept on the role of managers and management and the problems of implementing such an approach.

Concluding remarks by Chairman Warren Alberts summarized the benefits possible from this type of symposium as well as the need for different types of symposia in the future.

REFERENCES

(1) Alberts, Warren E., "Report to the Eighth AIIE National Conference on the System Simulation Symposium," *Journal of Industrial Engineering*, November-December, 1957.
(2) Report of System Simulation Symposium held May 16, 17, 1957. Available from: AIIE Headquarters, 32 West Fortieth Street, New York 18, New York for $1.75.
(3) Report of Second System Simulation Symposium held February 3, 4, 1959. Available from: AIIE Headquarters, 32 West Fortieth Street, New York 18, New York for $1.00.

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Reader Comments

CONTROL CHARTS FOR QUEUEING APPLICATIONS, by R. W. Llewellyn, *Journal of Industrial Engineering*, July-August, 1960.

I found the article, "Control Charts for Queueing Applications," which proposes a method of controlling queueing systems, very interesting. Mr. Llewellyn proposed controlling the queue length and was forced to deal with the difficulties of a skewed distribution. I believe that it would be easier to control the arrival rate and/or the service rate when looking for changes in a queueing system.

Control of the arrival rate is relatively simple; it is randomly distributed and the usual control chart techniques can be applied without variation. The difficulty and guess-work concerning the interval between observations is avoided. When controlling the arrival rate, a change is detected immediately, whereas a period of time can elapse before a change results in an abnormally long queue. When the queue length is out of control, additional studies have to be made to determine which phase of the system has changed—input or output. This second step is not required when controlling the arrival or service rates.

When the service rate is either constant or randomly distributed, it is just as easy to control and has all of the advantages of control of the arrival rate. If the service rate is badly skewed, control of the output function can be maintained by observing the performance of the operator directly with a control chart patterned after a work sampling or ratio delay study.—*Simeon E. Gordon, The Western Union Telegraph Company, New York.*

AUTHOR'S COMMENTS

I must agree with Mr. Gordon that there is more than one solution to this problem. I must also agree that, from a statistical viewpoint, control on the arrival and service rates is a more direct form of control than my suggestion of control of queue length. However, there are certain practical advantages to the latter approach. The n or $\bar{n}$ chart may be compared with the P chart of standard statistical quality control. We are charting a variable which is readily observable and which will indicate any change in the work situation while not identifying the source of the deviation.

If we attempt to control the arrival rate, a c chart will probably be adequate. But the matter of making observations is quite difficult.

1. We can use recording devices attached to the machine, if they are available or if management can be persuaded to make this not inconsiderable investment. But taking the data off of the individual machine records for each chart point is a considerable clerical task.

2. We can assign a person to observe the arrival rate at random times. We would need to use a period long enough so that the arrival rate is rather seldom zero, else our distribution will be at least as skewed as is the queue length distribution. In a man-machine situation, the incidence of stoppages is difficult to observe in a large assignment. If we follow the operator to obtain this information, we must use an observation period long enough to assure that we are not measuring the service rate rather than the arrival rate.

3. We can have the operator record the number of services per time unit, a rather unsatisfactory method.

Gathering information on service rate is about as difficult. If the man-machine situation is not a first down—first served system, as was the example in my paper, then service rate control is nearly impossible. In patrolling systems, for example, the effective service rate is a function of the number of machines down. In this particular situation there is an interaction between arrival rate and service rate, for an increase in the arrival rate decreases the average walk distance between machines and therefore increases the effective service rate. Of course, one can control actual service *time*, which should not include walk time, but this entails a time study type of observation which is a rather expensive method of gathering data for a control chart.

The n or $\bar{n}$ chart can be made from observations taken during one quick tour past the machine assignment, simply counting the machines that are not running. The difficulties involved in the analysis of possible deviations in the arrival rate or the service rate are precisely those we wish to avoid until the n or $\bar{n}$ chart indicates that such investigations are mandatory.

I do not agree with Mr. Gordon that a work sampling—based control chart would be effective in controlling the service rate. For, a change in the proportion of the total time spent servicing machines could be due to a change in the arrival rate (change in the number of services necessary) or to a change in the service method or pace (change in service time itself). Separation of these two factors would still be necessary. Since the variance of a proportion is large for small sample sizes, it would appear that the work sampling method would be prohibitively expensive as a permanent control.

In closing, I would like to note that there may be queueing applications other then man-machine situations where a more direct form of control would be the preferred approach.—*R. W. Llewellyn, Associate Professor of Industrial Engineering, North Carolina State College.*

SOLUTION METHODS FOR WAITING LINE PROBLEMS, by John R. Shelton, *Journal of Industrial Engineering*, July-August, 1960.

The following notes may be of pertinence in the use of John R. Shelton's article, "Solution Methods to Waiting Line Problems." These notes are not to be construed as forming a complete analysis of the article.

Note 1. The symbol "w" refers to the mean waiting time until the input unit enters the service facility. It does not contain, as is often the case, the time spent in the service facility.

Note 2. The symbol "L" refers to the mean number of individuals who are in the queue given that a queue exists. This symbol is often used (for example, Shelton's reference (13)) to refer to the mean number of individuals in both the waiting line and the service facility. Also the symbol L_q is an important measure which refers to the mean number of individuals in the queue.

Note 3. Eq. 10a could have been

$$L_q = wa = \frac{u^2}{1-u} \cdot \text{(13, p. 71)}$$

Note 4. For Eq. 13., either expression holds for $n = s$.

Note 5. Eq. 17a. could have been

$$L_q = wa = \frac{u(P>0)}{(1-u)} \cdot \text{(13, p. 103)}$$

Note 6. The symbol $P > 0$ is the probability that an arriving unit will find all of the channels occupied; that is, experience a delay. It is not the probability that a queue will exist. If an s-

channel system is in one of the states 0, 1, . . . $s-1$ the amount of $\alpha\%$ of the time and in states s, $s+1$, . . . an amount of $(100-\alpha)\%$ of the time, then the probability that an arriving unit will experience a delay corresponds to the amount of time during which the system is in states $s, s+1, \ldots$

Note 7. Eq. 33. should be

$$P > 0 = \sum_{n=1}^{n=N} P(n)$$

by definition of $P > 0$.

Note 8. Eq. 39. should be

$$P > 0 = \sum_{n=s}^{n=N} P(n)$$

by definition of $P > 0$.

Note 9. With reference to part 3 of the first illustrative problem, the required result should have been stated as follows: Find the probability of exceeding 5 minutes delay, $P > t/h$ or $P > 15$. Subsequent references to $P > 5$ should be $P > 15$.—*Thomas L. Newberry, Assistant Research Engineer, Georgia Institute of Technology.*

Editor's Note: The addition sign between the two sets of brackets in Eq. 11. should have been a division sign.

AUTHOR'S COMMENTS

I am very appreciative to receive Mr. Newberry's comments on our "Solution Methods to Waiting Line Problems" article which appeared in the July-August issue of the *Journal of Industrial Engineering.* I acquiesce in the substance of Notes 1, 2, 3, 4 and 5 of Mr. Newberry's letter of comments.

As for Notes 6 through 8 our formulas for $P > 0$ are consistent with the definition of symbols as outlined in the "Solution Methods for Waiting Line Problems" article. In connection with Note 9, I fail to see where use of the expression $P > 5$ leads to any ambiguity in understanding the illustrative problem.—*John R. Shelton, Chief, Operations Standards Division, The Port of New York Authority.*

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recent readables

AUTOMATION

"Don't Shy Away From Automation For Job Shop Operations," G. J. McManus, THE IRON AGE, *p. 107, June 30, 1960.*

Westinghouse automated a low-volume multi-model product line profitably. It developed a new concept, discarding old notions how and where automation could be used.

"Progress and Payoff in Industrial Automation," James R. Bright, DUN'S REVIEW AND MODERN INDUSTRY, *p. 44, January, 1960.*

Automation in the plant is already outstripping the predictions of 5 years ago, and it's paying off in many ways that have nothing to do with labor savings.

"What Happens to Employees When Offices Install Electronic Computers," THE OFFICE, *p. 118, June, 1960.*

Thanks to the Department of Labor's Bureau of Labor Statistics, here are some facts and figures on a subject that is causing concern in many areas.

"When the Computer Takes Over the Office," Ida R. Hoos, HARVARD BUSINESS REVIEW, *p. 102, July-August, 1960.*

A study of the impact of an organization when electronic data processing is installed. All classes of jobs, from office clerk to vice-president, are affected, quantitatively and qualitatively.

"Automation For Gas Blending," H. H. Sisk, OIL AND GAS JOURNAL, *p. 108, June 20, 1960.*

A case history showing how automation provided blending flexibility, eliminated uneconomical blending and improved use of manpower, storage capacity and safety. *(A. L. Friedrichs—Ethyl Corporation)*

COST CONTROL

"Do You Watch Office Costs As Closely As You Do Factory Costs," W. E. Mitchell, THE OFFICE, *p. 79, June, 1960.*

Some of the things that go on in offices would be considered outrageous were they to happen in the plant. Does this mean that the office is less efficient than the plant?

ENGINEERING ECONOMICS

"Some Considerations In Determining The Required Earnings Rate," Roger A. Golde, Gustav E. Brisard, THE ENGINEERING ECONOMIST, *Spring, 1960.*

This paper discusses the required earning rate with two main objectives in mind: 1. to consider, explicitly certain factors which have been talked about implicitly, or not at all, in current approaches to the required earning rate; 2. to suggest quantitative methods of handling some factors which up to now have been handled qualitatively, if at all.

"The Estimated Economic Life of an Investment Under Uncertainty," John H. McArthur, THE ENGINEERING ECONOMIST, *Spring, 1960.*

This paper explores certain problems surrounding the most commonly followed business practices with respect to the esti-

mated economic life of an investment proposal. It demonstrates that it is not possible to obtain a correct present value of an investment with an uncertain life by substitution of the expected life, in a present value formula, as a certainty equivalent.

GENERAL

"Ideological Pitfalls in Contemporary Management Practices," Alfred L. Thimm, ADVANCED MANAGEMENT, *p. 13, August, 1960.*

Management's ideological preoccupation with the wage employee and his union can be dangerous at a time when payments to nonproduction workers are increasing rapidly. More concern with modern organization is suggested.

"Critical Path Planning Means More Economical Turnarounds," OIL AND GAS JOURNAL, *p. 78, June 6, 1960.*

A new technique for planning maintenance and engineering jobs for most economical turnaround schedule. Does away with work order and spare parts forms. Uses Arrow Diagramming, Computation of standard time, Linear Programming ,and a Bar Graph of the job. *(A. L. Friedrichs—Ethyl Corporation)*

"It Doubled Output in Cedar Rapids," FACTORY, *September, 1960.*

Newest audio-visual tool for complex assembly operations and production training created by a former Hughes Aircraft Industrial Engineer. *(B. M. Bryant—Ethyl Corporation)*

INVESTMENT CONTROL

"Overnight Inventory Control," FACTORY, *September, 1960.*

How to have an up-to-date inventory report on manager's desk every morning in multi-plant operations. *(B. M. Bryant—Ethyl Corporation)*

"An Introduction to Inventory Management," Billie E. Goetz, ADVANCED MANAGEMENT, *July, 1960.*

This article deals with a major business problem: optimizing the utilization of working capital in the manufacturing phase by programming production schedules, in keeping with the most advantageous economic factors.

MATERIAL HANDLING

"Gasoline Engines—A Mainstay of Handling," by Editors, MATERIAL HANDLING ENGINEERING, *p. 60, August, 1960.*

The selection and maintenance of gasoline engines, as related to material handling is treated in this sixth article of the MHE Power series. *(N. E. Sparks—Ethyl Corporation)*

"Electronic Mail Handling Speeds Business Data," by Editors, MATERIAL HANDLING ENGINEERING, *p. 56, August, 1960.*

As part of the MHE series of special reports on paperwork handling, this article tells how the new 28-story Kaiser Center of Oakland, California uses a magnetic address system to move mail between a central mail room and between the 28 floors of offices. *(N. E. Sparks—Ethyl Corporation)*

"Building Unit Loads in 'Slices,'" by Editors, MODERN MATERIALS HANDLING, *p. 96, July, 1960.*

This article describes a new idea for building unit loads that saves 60% in labor, improves quality control and customer convenience. Loads assembled in vertical "slices" fit into progressive assembly methods with less reaching, and faster strapping. Its application to a brick and tile company is related. *(N. E. Sparks—Ethyl Corporation)*

"Colgate-Palmolive's Punched Card Order Picking," by Editors, MODERN MATERIALS HANDLING, *p. 81, July, 1960.*

Punched cards control 80% of the order picking in Colgate-Palmolive's newest toilet article warehouse. The article describes how this nicely integrated automatic and manual system can put through 9000 cases a day. *(N. E. Sparks—Ethyl Corporation)*

OPERATIONS RESEARCH

"Production Logic: A New Concept in Complete Management Thinking," Stanky Mantell, ADVANCED MANAGEMENT, *p. 6, August, 1960.*

The combination of logical production oriented thinking and the application of production control theory can establish criteria permitting top corporate management decisions in other fields—marketing and finance, for example.

"The Logistics of Distribution," John F. Magee, HARVARD BUSINESS REVIEW, *p. 89, July-August, 1960.*

The choice of distribution system each company makes will have a significant impact on product design investment, and organization. This article deals with better management of the flow of goods from plant to user. *(A. L. Friedrichs—Ethyl Corporation)*

QUALITY CONTROL

"Interpreting Reliability by Fitting Theoretical Distribution to Failure Data," W. S. Connor, INDUSTRIAL AND ENGINEERING CHEMISTRY, *April, 1960.*

By studying the failure history of a device, one can estimate and perhaps also learn something about how to improve reliability. *(B. M. Bryant—Ethyl Corporation)*

"Quality Control Gets Assist from Automatic Gaging," R. H. Eshelman, THE IRON AGE, *p. 130, June 16, 1960.*

Do your quality control programs tend to get too complex? Then automatic gaging might be just the thing to lighten the load. That is what it did for the GMC Truck and Coach plant.

"Management Looks at Quality Control," George H. Peck, INDUSTRIAL QUALITY CONTROL, *p. 42, May, 1960.*

The role of quality control is explained from a management viewpoint. Automation, reliability, personnel and operations research are among the topics discussed. *(J. L. Logan—Ethyl Corporation)*

WORK MEASUREMENT

"Work Sampling Techniques," A. C. Rosander, INDUSTRIAL QUALITY CONTROL, *p. 11, June, 1960.*

Several techniques which are very effective in a work sampling program are explained. The author shows why random time sampling works, explains how to design the sample and follow through with example problems and their solutions. *(J. P. Fagan—Ethyl Corporation)*

"How to Set A Profitable Office Work Pace," Charles A. Cerame, DUN'S REVIEW AND MODERN INDUSTRY, *August, 1960.*

Despite management's huge investment in typewriters, computers, copying devices, recording equipment, over the past 10 years office workers' productivity has actually declined—some experts think by as much as one-third.

"Yes, You Can Revise Your Incentive Plan," T. J. Wieczorek, FACTORY, *September, 1960.*

Too many company managers have let incentive plans run away with themselves—deteriorate to the point where their basic purpose of extra pay for extra effort no longer exists. What can be done to correct this situation. Mr. Wieczorek gives the answer in a five-step program. *(B. M. Bryant—Ethyl Corporation)*

SYSTEMS AND PROCEDURES

"Ratio Analysis: A System That Controls Production Profits," S. A. Tucker, THE IRON AGE, *p. 136, July 21, 1960.*

Sound analysis plays a vital role in predicting profits. The day has passed when a production manager was able to make safe judgments from data available at his finger tips.

"How Trust in Employees Saved 26 Million Forms in a Year," THE OFFICE, *p. 69, August, 1960.*

A work simplification program proved to this company that it pays to trust people. Eliminating many control forms improved employee morale. Savings in operating costs were passed on to customers in lower prices and annual profits increased.

"Make Payroll Change Lists Faster by Applying Rules of Probability," R. G. Martin, THE OFFICE, *p. 18, August, 1960.*

A change list for any size payroll can be made up in about three minutes by applying some simple rules of probability, whereas an exact change list on a large payroll may take an hour or more.

BOOKS

DYNAMIC MANAGEMENT IN INDUSTRY, *by Raymond Villers, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960, 516 pages, $10.00.*

A refreshingly modern treatment of management and Industrial Engineering.

CLASSICS IN MANAGEMENT, *by Harwood F. Merrill, American Management Association, New York, 1960, 446 pages.*

Excellent selections from the original writings of "Pioneers" in Management Philosophy—from Robert Owen (1771-1858) to Elton Mayo (1880-1949).

ORGANIZATIONAL BEHAVIOR, *by Grimshaw and Hennessey, McGraw-Hill Book Company, New York, 1960, 505 pages, $7.95.*

SETTING STANDARDS FOR EXECUTIVE PERFORMANCE, *by John Enell and George Haas, American Management Association, New York, 1960, 120 pages, $3.75.*

Treatment of an area of increasing importance and interest to Industrial Engineers.

MANAGEMENT OF TRAINING PROGRAMS, *by DePhillips, Berliner and Cribbin, Richard D. Irwin, Inc., Homewood, Illinois, 1960, 469 pages, $9.00.*

MANAGEMENT ORGANIZATION AND THE COMPUTER, *by G. P. Schultz and T. L. Whisler, publication of The Graduate School of Business, University of Chicago, published by Free Press of Glencoe, Illinois, 1960, 257 pages, $7.50.*

MANAGEMENT BY SYSTEM, *by Richard F. Neuschel, McGraw-Hill Book Company, New York, 1960, 359 pages, $7.95.*

SYSTEMS ANALYSIS FOR BUSINESS MANAGEMENT, *by Stanford L. Optner, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960, 276 pages, $8.00.*

ANALOGUE AND DIGITAL COMPUTERS, *by A. C. D. Haley and W. E. Scott (Advisory Editors) M. G. Say (Consulting Editor), Philosophical Library, Inc., 15 East Fortieth Street, New York 16, New York, 1960, 308 pages, $15.00.*

ENGINEERING ECONOMY, *by William T. Morris, Richard D. Irwin, Inc., Homewood, Illinois, 1960, 506 pages, $8.00.*

A refreshingly modern treatment of an old and important area.

PRINCIPLES AND DESIGN OF PRODUCTION CONTROL SYSTEMS, *by Scheele, Westerman and Wimmert, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960, 369 pages, $9.00.*

GAINING ACCEPTANCE FOR MAJOR METHODS CHANGES, *by Ben Miller, American Management Association, AMA Research Study 44, New York, 1960, 63 pages, $2.25.*

A thoughtful study of problems associated with office automation.

COLOUR IN INDUSTRY TODAY, *by Robert F. Wilson, The Macmillan Company, New York, 1960, 90 pages, $8.00.*

HOW TO CHART DATA, *by Phil Carroll, McGraw-Hill Book Company, Inc., New York, 1960, 260 pages, $7.50.*

An expansion and extension of "How to Chart Timestudy Data," including plant scheduling, control of costs, work measurement and other applications along with the basics of charting.

MANUAL OF EXPERIMENTAL STATISTICS, *by Freund, Livermore, and Miller, Prentice-Hall, Inc., New York, 1960, 132 pages, $5.30.*

AN INTRODUCTION TO LINEAR PROGRAMMING AND THE THEORY OF GAMES, *by S. Vajda, John Wiley and Sons, Inc., New York, 1960, 76 pages, $2.25.*

ENGINEERING ANALYSIS, *by Wen-Hsiung Li, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960, 362 pages, $11.00.*

METHODS OF REGIONAL ANALYSIS, *by Walter Isard, John Wiley and Sons, Inc., New York, 1960, 784 pages, $9.50.*

EDP IDEA FINDER, *by Canning, Sisson and Associates, Inc., Los Angeles, 1960, 656 pages, $69.00.*

A much needed compilation of significant ideas and information in a rapidly developing field, functionally organized in the following areas: EDP in Management; EDP System Design; Sociological Aspects of EDP; Equipment; Management Science; EDP Applications; and a list of supplementary resources.

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President's Comments

by **ALEX W. RATHE**

President of the American Institute of Industrial Engineers, 1960-61

Industrial Engineering Contributions to Managerial Planning and Control

In the first of this series (1), it was my privilege to report to you on the Resolution which the Board of Trustees adopted unanimously in May this year. It contained the broad objectives which have been set for the current operating year. And it reflected our sincere gratitude for the splendid achievements of those who preceded us in office. This enabled us to begin our work on the high plane to which they had lifted AIIE activities.

The second article (2) gave specific details on the major programs of the Institute. It sketched the services planned for individual members and for Chapters; and it discussed briefly our intentions with regard to internal administration and our relations with other branches of the profession, with management and the general public.

The reaction to both stories showed again the powerful part which the *Journal of Industrial Engineering* plays as the key communication medium between members and officers. Thus it is with real pleasure that I follow a number of suggestions received in response to these two presentations.

This as well as the following one or two issues will therefore reflect upon the contributions which Industrial Engineering has been making in its unique role as one of Management's mainstays. These pages will deal with the Industrial Engineer and the tasks he faces in Managerial Planning; the next will scan Industrial Engineering activities within the Management Control sector. If your response continues to support this approach, a third paper may attempt to take a look at Industrial Engineering and its work in Management Research.

As always, your comments are earnestly solicited since one of the prime objectives of the *Journal* is the dissemination of views for the explicit purpose of providing a forum for discussion.

DESIGN—THE ESSENCE OF ENGINEERING

BASICALLY, Engineering means *Design*. The ultimate objective of all engineering work is the creation of a blueprint. It sets forth a prescription which, when carried out as specified, is expected to bring predetermined results.

A statement as sweeping as that, covering some 600,000 or 700,000 practitioners, will obviously encounter some exceptions. Their examination shows, first, that many Engineers are busy in non-engineering work; secondly, the term "design" has to be taken in a broad but nevertheless justified sense; and finally, there do exist some instances, mainly in the field of Civil Engineering, where Engineers deliberately go beyond the confines of Design in staking out the scope of Engineering.

Further investigation of the thought proposed is thus in order. It may well produce additional and confirming evidence. Or it may generate such supplementary conclusions as to permit a later change in the concept. However until such facts come in, I shall disregard these exceptions in the interest of discussing here the heavy majority of situations in which the sphere of Engineering is Design.

Under these circumstances, engineering responsibility must include such tasks as

.. 1. *Analysis of the problems* which the Design should overcome.

Such activity calls, in many instances, for research so that the problems can be properly formulated and solved, if necessary, through the development of new knowledge.

This is followed by the *Development of specifications* which the Design should fulfill.

It includes the spelling out of the objectives which are to be accomplished; anticipated results must be fixed; other requirements—as to cost, quality, size, etc.—have to be settled.

.. 2. Actual *Design* work.

This is the heart of the engineering process, at least to the extent that, at the completion of this phase, the desired end result has been delivered.

.. 3. *Testing* of the Design against specifications.

If the verdict is satisfactory, the job is done. If it is not, the Engineer will have to go through one or several additional rounds comprising several or all of the tasks just outlined before he can sign off in the knowledge of having discharged his responsibility.

We are obviously talking here about a cyclical process: The conclusions from the test phase are the basis for any further re-analysis or re-design.

This recognition is significant because Management, too, is a cyclical process. In not-so-astounding parallel, Management and Engineering possess as their key components:

Engineering	Management
Specifications	Planning
DESIGN	OPERATIONS
Test	Control or Review

In both cases, the mission is shown on the second line: DESIGN and OPERATIONS, respectively. The first and third—Specifications and Test as well as Planning and Review—are helpers, service elements; their existence as justified only by the extent to which they contribute to the mission of each system, i.e., for the Engineer: successful design; for the Manager: successful operations.

Both Engineering and Management have further in common the utilization of Research and Development. As an auxiliary to their service elements, Research and Development analyzes and solves design and test (or planning and review) problems. Not infrequently is it necessary for Research first to develop new knowledge before the problems can be cracked.

For the Engineer as well as the Manager, the generation of such new insights is a means to an end; for the Scientist, it is the end itself, the very objective of his work.

We can draw one other conclusion from these observations: Industrial Engineering can be operative anywhere in Management where executives are concerned with:

.. Design, i.e. planning, and test, i.e. control or review.
.. Problem solution, i.e. research.

An Engineer, *as a practitioner of Engineering*, is a stranger in the Operations sector of Management. This basic limitation does not contradict the fact that many (Industrial) Engineers have been highly successful in management work. However before such results could be achieved, these men and women had to possess and develop special personal traits; they needed to gain experience beyond that required in Engineering as well as to acquire a lot of additional knowledge.

Applying these ideas to the various specialty branches of Engineering, it becomes clear that all of them, with the sole exception of Industrial Engineering, provide designs (of products, structures, processes, etc.) *for* Management. Industrial Engineering, on the other hand, produces designs *of* Management.

History and practice supply a generous assortment of examples on how Engineering in general has contributed to the tremendous change in the appearance of life on this planet in recent decades. And the same sources can be just as readily called upon to testify to the large number of instances in which Industrial Engineering has met the equally imposing challenges of changes which have been—still are—taking place in Management.

THE INDUSTRIAL ENGINEER IN MANAGERIAL PLANNING—SCOPE OF PLANNING

Fundamentally, Managerial Planning endeavors to answer all major questions in advance which must be resolved before Operations could expect to move smoothly. They can be grouped into two distinct but interwoven categories:

.. 1. The establishment of Goals.
What is the objective, the mission of the work involved?
What action is need to fulfill it?
What is its cost? Its investment requirement?

.. 2. The design of the best approach to these targets.
Who is most suited to carry out the various tasks?
When and where are they to be performed?
How are they done best?

Contrary to logic which becomes clearer with the wisdom of hindsight, historic developments did not start with the first but with the second of these two groups. As a matter of fact, it began with the last, the question of: *How* shall action proceed?

DESIGNING THE APPROACH

And one of the earliest planning techniques which addresses itself to this matter, is also one of Industrial Engineering's oldest roots: Motion Study-Methods Engineering, with its function to design the best way to perform an operation.

The methods area of Industrial Engineering in its never-ending search for ever-better means carries with it a most powerful philosophy, the spirit of Productivity. As guardians of this mighty concept, we are entrusted

with an obligation of deepest significance to the country and the world.

When I recap here, much too briefly, the magnificent developments of Methods Engineering, a story unfolds which is repeated in other phases of Industrial Engineering as well. In most of them, the original concern was with production operations alone. But soon the scope widened; the same approach proved itself equally sound in the support functions of production, then beyond the factory itself, in non-manufacturing industry and finally in many other commercial and non-profit activities, too.

Methods Engineering, for instance, began early to include in its production method design such additional responsibilities as:

.. Designation of feeds and speeds,
.. Development of fixtures and dies, of tools and equipment,
.. Consideration of materials handling, flow and layout,
.. Safety measures,
.. And still other aspects.

On its forward march, Methods Engineering has become engaged

.. at first in:
—Plant maintenance,
—Inspection,
—Stock handling,
—The toolroom,
—And other production support departments,
.. and then in:
—Clerical work,
—Sales activities,
—Indeed in any other function, section or group where repetitive work occurs sufficiently often to warrant advance study of the way in which operations can proceed best.

An interesting sidelight on the sweep of Methods Engineering is its relation to one of the newest additions to the business scene, the Computer. Its programming depends in many ways on precisely the same principles which have governed Methods Engineering for decades.

Today, methods and all other phases of Industrial Engineering—under these or different labels—are actively and successfully employed in just about every kind of human endeavor, i.e. in:

.. Manufacturing and Mining,
.. Construction,
.. Transportation, Communications and Public Utilities,
.. Wholesaling and Retailing,
.. Agriculture,
.. Financial Institutions, Real Estate and Insurance Firms,
.. Service Business,
.. Entertainment, Sports and Recreation,
.. Non-profit organizations (such as hospitals, education, government),
.. You name the field; if it is progressive, it employs Industrial Engineering.

Methods Engineering thus answers one key question of Managerial Planning: *How* shall action go on? Its logical counterpart is *How Much?* We need to know, for example:

.. How much do we have to use of each of the key resources required for the management of the work (input)?
.. How much do we expect to find of each of the decisive components of successful performance (output)?

Industrial Engineering established an early beachhead on this growing complex of managerial concern. Through Time Study, Production Planning and other techniques, it developed Time Standards which became the basis of many planning aids, including:

.. Work schedules,
.. Equipment load schedules,
.. Progress schedules,
.. Delivery schedules,
.. Material allocation schedules,
.. And many more.

Some of these answer two additional crucial planning questions, namely *Where* and *When*. As in the case of Methods Engineering, the basic techniques which grew up at first in production, are proving themselves in many other activities as well.

However records of past accomplishments also indicate that many practitioners of Industrial Engineering have shown a tendency to limit themselves to the development of Time Standards. Obviously other factors, beyond Time despite its great significance, are also important in human activity. There are:

.. Cost,
.. Quantity,
.. Quality,
.. Distance,
.. Performance,
.. The vast basket of human considerations,
.. And still many others.

In these, Industrial Engineering has not yet produced as promising results as it has generated in the area of time standards. Especially with regard to measures of individuals and groups, an objective appraisal of contemporary achievements sees Psychologists busily engaged in such work to which they refer not infrequently as "Engineering Psychology."

This comment is not intended to raise a cry of jurisdictional infringement. On the contrary, it wishes to be interpreted as an urgent suggestion for the Industrial Engineer to realize that the foundation of his knowledge does not only rest in the technical but in the living sciences (and indeed in mathematics) as well.

A fifth key question of managerial planning concern is: *Who* is doing what has to be done? The techniques involved are best summarized under the umbrella term of "Organization."

Organizational design aims at the distribution of the sum total of tasks which is required for the work at hand; it results in the delegation of the responsibility for specified assignments to specific people.

The foremost gift which Organization has acquired in the past, are the contributions which Industrial Engineer-

ing has made to the problems of constructing a framework for the enterprise and its operations. They are far-reaching and sound. They are bound to retain their lasting strength. But they may have to relinquish this seat of honor in the years to come.

Future progress in Organization is more likely to come from research in the behavioral sciences. When it gathers momentum, it will bring lavish dividends as it enriches the knowledge about the as yet most unpredictable "thing" in all creation: The human being—as an individual and, collectively, in a group.

Organization is thus another one of the growing number of witnesses who testify to the pressing need for the Industrial Engineer to temper our technical experience with the wisdom distilled from life itself. We have to use our engineering know how to the limit. But we have to alloy it with the heart and feelings whose lack one of our profession's all-time Great, Henry L. Gantt, deplored more than forty years ago.

ESTABLISHING GOALS

Two major questions still remain to be answered before management planning is complete. The *What* and *Why* of all action. They clearly constitute the crux; we first must know what has to be done and why before consideration of how, how much, when and where or even who can exercise its full weight.

And it is in these crucial sectors of planning that Industrial Engineering's presence is least prominent. Yet the work involved is design in the purest sense. The scarcity with which we have contributed to this field of endeavor, holds by this very fact the promise of a huge potential.

The executive planning arsenal has developed strongly in the past ten years or so. Today it is one of the accepted hallmarks of far-sighted management if planning activities include Operating Programs and Long Range Plans. The latter outline specific goals for selected Company functions. Speaking in terms of a manufacturing firm, they are likely to center around:

.. 1. The development of more useful products and services.

Smith, Kline and French Laboratories, for instance, reported just recently that something like 60% of their current sales come from products which are less than three years old. True, the pharmaceutical industry is one in which change has raged with more power in recent years than has been the case in many others. But is change not one of the Industrial Engineer's prime objectives—*as long as it brings progress?*

Change just for change's sake is farthest from my mind in advocating wider Industrial Engineering participation in corporate planning. Too many examples of harmful effects can be cited where management altered matters mainly to produce a new model every year.

The detrimental consequences of such an attitude may become obvious to many only after some years of seemingly delightful results. Yet the seeds of the downfall are inescapably fused into any design whose mission is to displace a good thing without adding some better value.

The Industrial Engineering record is replete with examples of skill in helping in the development of more useful designs. All its attendant problems of creativity in conceiving the new thing in the first place, and then the evaluation of many and at times bewilderingly different alternates are intrinsic in the mission of Industrial Engineering. And our field serves with equal effectiveness in the design of how to manage.

.. 2. The necessary manufacturing and market support for such new products as well as the needed financial and personnel resources.

Its talents have proved themselves even more in the design of management for the purpose of:

.. 3. Capitalizing on existing strengths and mitigating current weaknesses.

This third major area of Long Range Plans exists in every organization. Industrial Engineering is uniquely qualified to put its shoulder to the wheel in ferreting out the characteristics which belong into these two categories; in addition, it is our mandate to know how to design ways and means by which the plus factors can be utilized and the minus elements curbed increasingly.

Long Range Plans peer ahead five, ten or even more years. Operating Programs generally concern themselves with the next six or twelve months. They spell out the immediate action which should be taken in all company activities. They can comprise as large a scope in each enterprise as there are functions.

No stranger in manufacturing indeed, the Industrial Engineer has long had, for instance, the lead hand in designing Work Simplification Programs. There are other and equally important problems in production management. Many satisfied customers can relate how effectively Industrial Engineering has contributed to the design of such other operating programs as:

.. In the Manufacturing Division
  —Purchasing programs
  —Materials inventory programs
  —Quality improvement programs
  —Labor supply programs
  —Manufacturing service programs
.. In the Marketing Division
  —Merchandising programs
  —Sales programs
.. In the Personnel Division
  —Recruitment programs
  —Training programs
.. In the Financial Division
  —Cash and working capital programs
  —Investment programs
.. And similarly in any other Division.

One large field which is closely connected with operating programs is Budgeting. Again there are many instances for the effective role which Industrial Engineering is playing in the formulation of budgets. After all, they are fundamentally these same operating programs but expressed in financial terms, i.e. translated into specific figures for capital and operating expenses.

Long Range Plans and Operating Programs state what action is planned for the organization. This leaves the last question: *Why*—the reason for all this activity. The response to this is scanty not only when we ask Industrial Engineers but also when we turn to Management itself.

An entire book could—possibly should—be written which treats with this problem. These columns are much too limited to permit an adequate discussion. May I restrict myself therefore to these few lines: Just what is the purpose of a specific organization? Why does it exist?

Obviously, "profit" has been the reply most widely accepted for decades. Just as obviously, it is correct but it does not suffice. If it did, why do we have so many firms die every year although they operated in the black? Why are there non-profit organizations?

Some of management's foremost practitioners believe that the generation of profits while unquestionably a key purpose of corporate life in our economy, must be joined by the creation of other values to assume economically lucrative and socially acceptable results from the workings of any enterprise.

When faced with the challenge to investigate problems, to analyze their complex content and to devise possible solutions, the Industrial Engineer has proved his abilities over and over again. Just such a case confronts Management in the formulation of its corporate objectives (and the subsidiary objectives of each of its components).

As this field is one in which little thought has yet been given beyond a rather exclusive circle of the most progressive managements in this country, the Industrial Engineer may find in his participation in this work another challenge of immense scope. Moreover, even exploratory and preliminary results would be bound to have a vast impact upon our economy and the country as a whole. Occupation with these problems would subject our *professional* fibre to an acid test where it counts most because the solutions must stand up in the crucibles of business operations.

A PROPER PARTNERSHIP IN PLANNING

In most companies, Planning has attracted top management interest especially within the past ten to fifteen years. Its concern has increased spectacularly as evidence began to show what Planning can do to help maximize Profit and Service. Industrial Engineers have been active in the very first planning efforts of modern business. We are engaged today in every conceivable facet of managerial planning. But we are not yet so occupied in every possible company.

This situation holds a uniquely high opportunity. Industrial Engineering will show—in a period of surprisingly few years, I am sure—that it can strengthen managerial success with its engineering know how just as surely in the *what* and *why* sectors as it has proved itself so convincingly in the other segments of planning.

The expansion of Industrial Engineering into the full complement of all the planning areas is well underway. Since this development could have taken place years ago, its late start represents an additional incentive to catch up. This field is a natural for the men and women in our branch of the profession as planning means design and design is the quintessence of Engineering.

REFERENCES

(1) Rathe, Alex W., "The Road Ahead," *The Journal of Industrial Engineering*, July-August, 1960.

(2) Rathe, Alex W., "The New Industrial Engineer," *The Journal of Industrial Engineering*, September-October, 1960.

ENGINEERS JOINT COUNCIL MISSION TO RUSSIA

The objective of the mission was basically to study the utilization of engineers and engineering technicians and their interrelationship in the Soviet Union. Starting with their graduation from the engineering institutes and technicums we hoped to learn how the graduates started out in industry, what their training on the job was, what sort of work they did, and how they worked themselves up within their profession. It turned out, however, that as our host was the Ministry of Higher and Secondary Education, the majority of our visits were to educational establishments. Our itinerary covered Moscow, Leningrad, Kharkov, Rostov, Baku and Tashkent with a side trip to Samarkand. In all, we visited 13 technical institutes, three technicums and five industrial plants, or enterprises as they are called there.

We were graciously received everywhere. There was plenty of evidence of the desire for friendship between our peoples whether it was in our meetings or just in the street. We were always treated with courtesy, politeness and friendliness.

Our trip was one of only four weeks. Our observations were limited by the few cities we were able to visit and by the few enterprises which we were able to see. Nevertheless, we did come back with some definite impressions and conclusions which we feel should be of interest to engineers, educators and those concerned with the relative economic and technical power of the U.S.S.R. and the United States.

First, although the quality of engineering education had previously been studied by Korol of MIT and DeWitt of Harvard, as well as by the ASEE team in 1957, we had the opportunity to observe that significant changes have been and are being made in the Soviet Union. Following a 1957 decree the goal is to admit not more than 20 percent of their high school students directly to higher education, to the vuzes, the remaining 80 percent have to spend two years in practical work in industry before being permitted to continue their education. Even the 20 percent directly admitted are required, as part of their education, to spend one year and four months in practical work in industry. Furthermore, since so much practical training is being received while working in industry under the guidance of institute faculty members who

accompany the students to the enterprises, it has become possible, as well as desirable, to strengthen considerably the theoretical content of the engineering program.

Thus, we can say that the engineering education given in those institutes in the U.S.S.R. which we visited is of high quality. Theoretical and mathematical content are above that generally given in the bachelor programs in the United States engineering colleges. This is combined with practical specialization to a large extent. Foreign languages and political economy are included in the curricula, but not the more humanistic social courses which we give.

Second, technicums operate an efficient and effective program to produce technicians. The mathematical content of the course work is above that of practically all the technical institutes in the United States. Representatives of the Ministry of Higher and Secondary Education stated that the U.S.S.R. is producing 250,000 industrial technicum graduates annually for industry, while we in the United States graduate 14,000 to 16,000 annually of whom not over 1,000 are of the quality of those produced by the technicums we visited. Also a considerable number of technicum graduates go on in engineering education to qualify as engineers. There seems to be little question but that enterprises are utilizing technicians to support effectively the work of engineers in research, design and production.

Third, although some 108,000 engineers are graduating each year in the U.S.S.R. we did get the impression that many are assigned to jobs to which we would not assign engineers in this country. It is not uncommon, apparently, for an engineer, on his first assignment to serve as a technician or even in the worker category.

About one third of the students in engineering institutes and technicums are women, and they are employed in a wide range of technical positions. It seems, however, that a smaller percentage hold top administrative positions in enterprises and education.

One of the most impressive things was the broad program of continuing education through evening, correspondence and upgrading and refresher courses which provide opportunities for large numbers of men and women in all levels to continue their technical education. There is no question but that Soviet citizens approach technical education with great seriousness of purpose and real dedication. They know that it is one of the principal avenues to higher status and economic privilege. This results in an extremely high motivation in both institutes and technicums which helps to account for the very low attrition rates (less than 5 percent in the daytime division, and 10-15 percent in the evening and correspondence divisions). Another important motivation factor, of course, is the stipends which are given to 75-80 percent of all students on the basis of academic performance. Again, engineering education positions which come, in general, only after many years of experience in industry plus post graduate study, carry more status and financial compensation than industrial positions.

Under the new system all technical education has been closely integrated with industry. In this way, the graduates may be effectively utilized by industry immediately after graduation, because of the practical work experience obtained at the enterprises during the educational process. The faculties of the technical institutions, aided by their students, are continually called upon by the enterprises to solve many of their problems. This close cooperation is of great benefit to all concerned.

In general, it seems to us that the system of personnel planning and distribution of graduates is appropriate to the Soviet Union's planned economy, and it seems to work smoothly and economically enough in a way that appears to offer the technical person a considerable degree of freedom of job choice within his speciality.

Our plant visits, although relatively few and limited to well established industries and which included none of the newer highly automated plants did bear out, so far as we could ascertain, the information relative to engineer and technician use which we gathered from educational establishments.

Summarizing, we believe that we can learn something from our visit. We must not discount the technical education which is being given increasingly throughout the Soviet Union. The drive to learn, with appreciation by all of the importance and impact of technology in today's world is something to which we can well give serious thought. We are in a highly competitive world situation and we want to maintain our position.

SIGNIFICANT QUESTIONS AND ANSWERS

Q—Are the Soviets concentrating on turning out specialists or on engineers with a broad training?

A—Engineering students are given basic instruction programs, on top of which they receive highly specialized training *within* their institutions. In the United States, a student generally receives his specialized training in industry.

Q—How many years does the Soviet curriculum require?

A—Five-and-a-half. This generally involves a four-year academic course plus 1½ years practical training.

Q—Are Soviet students more serious than Americans?

A—Yes. There seems among undergraduate students almost a coercive motivation to succeed. The institutions apparently do not waste time with borderline students. All schools visited had admitted only one out of every four applicants.

Q—How does the American "C" average compare to the Soviet average student?

A—The fact that 75% or better receive stipends for academic accomplishment indicates a higher average.

Q—Does Russia have professional registration of engineers?

A—There are 25 "so-called" technical societies.

Q—How about the women engineers?

A—It is our impression that women engineers do not reach top positions. The motivation to train women engineers is apparently one of "need" rather than desire for equal opportunity.

Q—To what extent are top engineers party members?

A—It appeared that at least 75 percent of engineering managers are Communist Party members.

Q—What did you learn that you could apply to American education?

A—Primarily that we must become more serious in our view toward education. Also, that early channeling of students into specialties might be nice for us, but it would cost us more than we are willing to pay: our students would lose their freedom of choice.

INDUSTRIAL ENGINEER WITH PROCESS ENGINEERING BACKGROUND

Progressive multi-product industry located in the Pacific Northwest requires an Industrial Engineer experienced in Machine Shop and/or Plate Shop manufacturing methods; must be able to do Process Engineering from standard data. Experience desired in making economical and cost-reduction studies. Excellent advancement potential for qualified engineer. Salary open. Will pay relocation expenses. Resume will be kept in strict confidence.

Write:

Box I
Journal of Industrial Engineering
A French Building, 225 North Avenue, N.W.
Atlanta 13, Georgia

Institute Interests

CALENDAR

November 27-December 2: American Society of Mechanical Engineers Annual Meeting, Statler-Hilton Hotel, New York, N.Y. Write: L. S. Dennegar, ASME, 29 West 39th St., New York 18, N.Y.

*December 7: "Applying IE Skills to Non-Manufacturing Areas." Speaker: Robert Frankel, Subscription Service Manager, *Reader's Digest*.

December 26-31: One Hundred Twenty-Seventh Annual Meeting, American Association for the Advancement of Science, Philadelphia, Pennsylvania.

*January 4: "Various Techniques of Time Study: Approaches to Improve Accuracy." Speaker: Mitchell Fein, Consultant IE, PE.

*January 16: "Profit Planning with Budgetary Control." Speaker: Arthur Seccia, Director of Budgets and Cost Analysis, American Air Lines.

January 23-February 2: The 1961 Engineering and Management Course, Los Angeles Campus of the University of California. Write: Reno R. Cole, Coordinator, College of Engineering, University of California, Los Angeles 24, Calif.

*February 1: "Organizing and Maintaining a Quality Control Function." Speaker: Jack Keyser, Bell Telephone Laboratories.

*February 20: "Strategic Planning and Decision Making." Speaker: Dr. Herbert Jacobs, Dunlap & Associates.

*March 1: "How to Raise Productivity Through Better Supervision." Speaker: Dr. Raymond A. Katzell, Professor of Management Engineering & Psychology, NYU, College of Engineering & Director of Research Center of Industrial Behavior.

March 2-12: Third Inter-American Management Conference, Mexico City, Mexico. Write: Colonel Philip Garey, Vice President of Operations, Council for International Progress in Management, 247 Park Avenue, New York 17, N.Y.

*March 20: Forum on IE Problems as they affect Labor-Management Relations. Panel of Union, Management & Arbitrator Representatives. Moderator: Irving Gurfield, Attorney & Practicing IE, Barricini Candies.

March 20-31: Industrial Packaging Short Course, Purdue University Campus, Lafayette, Indiana. Write: Mark E. Ocker, Conference Coordinator, Division of Adult Education, Memorial Center, Purdue University, Lafayette, Indiana.

*April 5: "The IE Approach to Cost Reduction Through Cost Controls." Speaker: Dr. Alex W. Rathe, National President AIIE, Professor of IE, NYU, College of Engineering.

April 12-14: Purdue University's third Symposium on Information and Decision Processes, Purdue University, Purdue, Indiana.

*April 17: "Management Controls by Ratio Analysis." Speaker: Spencer A. Tucker, Partner, Martin & Tucker, Consultant IE's.

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*AIIE Metropolitan New York Chapter Workshop Subjects. All meetings held at National Cash Register Auditorium, 50 Rockefeller Plaza, New York City, at 7:00 P.M. Director of Workshops: Mitchell Fein.

PROPOSED AMENDMENTS TO AIIE BYLAWS

The AIIE Constitution and Bylaws Committee recommend the following changes or additions to the present bylaws:

1. *Article V. Section 1,* which now reads:

"The fiscal year shall be October 1 through September 30" amended to read:

"The fiscal year shall be July 1 through June 30"

This recommendation is based on action by the Executive Committee on June 24-25 (item 4—page 7).

2. *Article VI, Section 10 (New Section)*

To permit the proper filing of our application for a 501 (C)(3) tax classification, our attorney has requested the attached bylaw "prohibition against sharing in corporate earnings" be approved by the Board of Trustees. This bylaw has been reviewed by the constitution and bylaws committee and recommended for approval.

Prohibition Against Sharing in Corporate Earnings

No member, trustee, officer, or employee of, or member of a committee of, or person connected with the corporation, or any other private individual shall receive at any time any of the net earnings or pecuniary profit from the operations of the corporation, provided that this shall not prevent the payment to any such person, of such reasonable compensation for services rendered to or for the corporation in effecting any of its purposes as shall be fixed by the board of directors and no such person or persons shall be entitled to share in the distribution of any of the corporate assets upon the dissolution of the corporation. All members of the corporation shall be deemed to have expressly consented and agreed that upon such dissolution or winding up of the affairs of the corporation, whether voluntary or involuntary, the assets of the corporation then remaining in the hands of the board of directors, shall be distributed, transferred, conveyed, delivered, and paid over to exclusively scientific, educational or charitable institutions upon such terms and conditions, and in such amounts and proportions as the board of directors may impose and determine, to be used by such institutions receiving the same for such similar or kindred purposes as are set forth in the certificate of incorporation of the corporation, and any and all amendments thereto.

THE DWIGHT D. GARDNER SCHOLARSHIP FUND

William E. Brown, a student of Industrial Engineering at Ohio State University, Columbus, Ohio, was selected as recipient of the Dwight D. Gardner Scholarship award for the year 1960-61. The scholarship fund was set up by the American Institute of Industrial Engineers (a national engineering society) in honor of their first elected national president, and was established to aid in the furtherance of engineering education.

Mr. Brown's selection was announced in Columbus by J. L. Southern, president of the scholarship fund. The scholarship is for the amount of $750. Mr. Brown was chosen from a field of 17 applicants. He has been a student in Industrial Engineering at Ohio State University since the autumn of 1956. He served 4 years in the armed forces in the United States Air Force and was graduated from high school in Salineville, Ohio. He is a member of Tau Beta Pi and Alpha Pi Mu, engineering honorary organizations.

Mr. Brown is married and makes his home at 501 Jefferson Street, Salineville, Ohio.

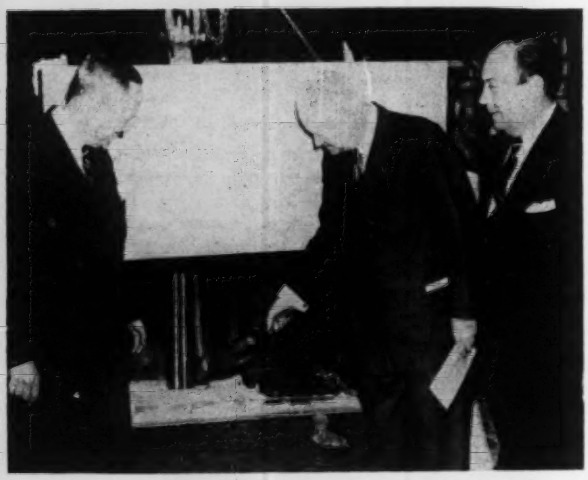
NEWARK COLLEGE OF ENGINEERING

Under a $10,000 grant from the United States Small Business Administration, the NCE Department of Industrial and Management Engineering this summer studied the utilization of Industrial Engineering techniques in small plants.

The grant was obtained and administered by the NCE Research Foundation. Professor Oliver J. Sizelove was project director. He was assisted by four other faculty members.

The study proceeded through questionnaires to 2,200 small industrial plants in New Jersey and in New York and depth interviews with administrators at about 75 of the plants. The investigators planned to learn the extent to which small plants could use modern production techniques successfully employed in larger plants.

UNITED ENGINEERING CENTER



FORMER PRESIDENT HERBERT HOOVER was guest of honor at recent cornerstone-laying ceremonies for the United Engineering Center in New York City. At left is Andrew Fletcher, President of United Engineering Trustees, Inc., and at right, Mayor Robert Wagner.

PERSONALITIES

DR. LAWRENCE W. WALLACE

Dr. Wallace has been commended for Meritorious Civilian Service by the Department of the Army. The official commendation for outstanding performance of duty reads:

"Citation: For Meritorious perf. mance of duty as Training Officer, (Industrial Management), Ordnance Management Engineering Training Agency, Ordnance Weapons Command, Rock Island, Illinois, from 22 June 1952 to 1 January 1959. His thorough knowledge of management and management engineering and his outstanding ability to imbue and propagate management principles to students of the field reflects great credit to the successful operation and advancement of many programs for the Ordnance Corps as well as other Department of Defenses agencies.

(Signed) J. H. Hinrichs
Lieutenant General, USA
Chief of Ordnance"

We extend our sincere congratulations to Dr. Wallace on his receipt of this highest award the Department of the Army grants a civilian.

METROPOLITAN NEW JERSEY CHAPTER

On June 28, 1960, the members of the Metropolitan New Jersey Chapter of AIIE toured the General Motors assembly plant in Linden, New Jersey. The plant safety director, Mr. Jack Cavanagh, guided the members through a plant which represents the epitome of production control. No corner of the plant was overlooked and an interesting and enjoyable time was had by all. At the conclusion of the tour a brief meeting was held during which Dan Mandel, our 1959-60 chapter president was awarded the past president's pin. Dan, in turn, passed the gavel to Erv Eggiman, our new president, who listed the 1962 national convention and the consideration of geographical chapter reorganization as important work that lies ahead.

The Metropolitan New Jersey Chapter has received a chapter development award of excellence. Lehigh Valley recived the regional award.

ST. LOUIS CHAPTER

The St. Louis Chapter held a "Pre-season warm-up" at Barth's Estate on Thursday, August 25. This was a wonderful opportunity for members to get acquainted with the new officers and committee chairmen, and for plans and programs for the coming year to be discussed. In addition to the business at hand, members enjoyed a picnic style lunch, pingpong, badminton, horseshoes, and swimming. This is the second year we have enjoyed such a meeting, and plan to make it an annual event.

SPRINGFIELD CHAPTER

Springfield Chapter No. 94 completed its first full season last June. Under President James E. Johnson, Associated Engineers Inc., the Chapter established a precedent by presenting to its members and guests a monthly program of high interest level arranged by Program Chairman James P. O'Brien, Chapman Valve Manufacturing Company. The successful dinner meetings, held in October and November, were followed in December with guest speaker Arnold A. Putnam, Director of Research for the consulting firm of Rath and Strong. His topic was centered on "Indirect Incentives—Measurement and Techniques." This meeting also saw the election of Edward A. Marti, Asst. Chief Industrial Engineer for William Carter Co. as treasurer to fill the vacancy created by the relocation of Robert J. Munns to New Jersey.

In January, many of the members and guests were introduced to the relatively new metal cutting development "numerical tape controlled machines." The introduction was made by David N. Smith, Chief Development Engineer for Jones and Lamson Machine Co. He also outlined the effect this recent development could have on Industrial Engineering. Programming diversification was continued in February. At this meeting, Edward Binshadler, managing consultant for the certified public accounting firm of Arthur Young, Inc., outlined the fundamentals and techniques employed in the use of "variable budgets" and described some of the advantages of this modern tool over the "static" budgets.

The first anniversary of the granting of the charter to the Chapter was marked with the Chapter's most ambitious program for the March meeting. The program was initiated with a plant tour of Springfield Armory in the afternoon. The members and guests greeted by Col. C. L. P. Medinnis, commanding officer, were permitted to view, in operation, some of the most modern production equipment used in the manufacture of small arms weapons. Some of the most impressive included high speed woodworking machines, numerical tape controlled jig bore machines, electronically controlled magna-spark profiling machines, ultrasonic cleaning equipment, and a variety of single purpose multi-station drilling and milling machines. In addition to viewing, we also heard the acceptance firing of the new M14 rifle and the M60 machine gun. We also witnessed the gunsmithing required to produce the refined rifles used in the National Matches. We then visited the world renowned Springfield Armory Museum of Small Arms. In addition, to seeing all types, sizes and kinds of small arms weapons, we were all impressed by the rack of Civil War rifles

Left to right, Henry M. Owades, Vice President of Region I, AIIE; James P. O'Brien, President; David E. Cahill, Jr., Vice President; Edward A. Marti, Treasurer; Andrew D. Poggi, Secretary.

immortalized by Poet Henry Wadsworth Longfellow in his poem "Organ of Guns."

Our tour was followed by a social hour and dinner. In the evening, the program was climaxed by a panel discussion on "Springfield Armory Today." Another precedent was established by having, for the first time in the long history of Springfield Armory, the chiefs of the four operating divisions participate publicly as a group. The division chiefs who served as panel members were: Herman F. Hawthorne, Research and Development; Harry F. Lynch, Engineering Division; George G. Mackintosh, Operations Division; and James V. Rowley, Inspection Division. The panel discussion, in addition to newspaper coverage, was covered by one of the local TV stations for its news program. President Johnson and Program Chairman O'Brien were assisted in arranging the program by Charter President Benjamin F. Ridall and Theodore J. Trudeau, both of Springfield Armory.

The April meeting was highlighted by guest speaker C. W. Carter, industrial management consultant, Longmeadow, Massachusetts. He spoke on "Statistical Engineering." Nominations for the 1960-1961 season officers were submitted by the nominating committee chairman Robert P. Warriner, William Carter Company.

The May meeting was a triple feature: "Ladies Night," election of officers, and Vice President of Region I, Henry M. Owades. Mr. Owades, in addition to installing the officers, described some of the activities of the National Convention. His presentation of "Industrial Engineering in the 60's" was inspiring and greatly enjoyed by both the members and the ladies. The elected officers are: President James P. O'Brien, Chapman Valve Mfg. Co.; Vice President David E. Cahill, Jr., Worthington Corp.; Treasurer Edward A. Marti, Wm. H. Carter Co.; and Secretary Andrew D. Poggi, Buxton, Inc.

WINSTON-SALEM CHAPTER

The Winston-Salem Chapter has lined up a number of interesting programs for the 1960-1961 season. Our program for September was on the topic of Chapter Development. Mr. C. T. Johnson of R. J. Reynolds Tobacco Co. spoke to us on "Measuring Chapter Performance Against Standards." Student Recognition was the theme of the October meeting. Mr. Ray Gibbs, Superintendent of County Schools, and Dr. Robert Hanes, Director of Secondary Education in the Winston-Salem Schools, were guest speakers.

The coming year holds two planned plant tours: In November, we will tour the Chatham Manufacturing Co., and in February, the Winston Printing Co. We are fortunate to have Alex Rathe, President of AIIE, as our promised speaker at the January meeting. In February, there will be our annual Joint SAM-AIIE Conference, with its topic of Motion and Time Study. Plant Engineering will be the subject of the April meeting, with Mr. W. C. Wallin of Western Electric Co. as guest speaker. We will wind up the 1960-61 season in June with our annual Ladies' Night.

12th Annual

AIIE NATIONAL CONFERENCE AND CONVENTION

May 11, 12, 13, 1961

Sheraton Cadillac Hotel

Detroit, Michigan

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ie opportunities

The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Metropolitan New York chapter.

SERVICES PROVIDED

Current job openings are published in condensed form in each issue. In addition, a monthly I. E. Opportunities Bulletin is supplied to over one hundred chapters located throughout the U.S.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

MEMBERS SEEKING JOB OPPORTUNITIES

The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

ADDRESS OF THE SERVICE

I. E. Opportunities Service
American Institute of Industrial Engineers
32 West Fortieth Street
New York 18, New York

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
41	Consulting	Ohio	×	10, 21, 31		5–7		
167	Weapons Systems	Wash. D.C.		50				Ph.D.
213	Air Force	Calif.		15, 32, 42, 43, 44, 53	7.5–	2½–	21–	Repair & Modification
273	Air Force	Utah		11, 13, 18, 42, 43, 44, 53	6.3– 7.5	2–		I.E. Degree
279	Air Line	Ill., Colo., Calif.		11, 13, 18, 41–43, 50–52, 70	6.0–10.0	1–6		
423	Air Force	Ohio		Broad	8.8			I.E. Degree
424	Air Force	Ohio		Broad	4.5– 7.5			I.E. Degree
449	Electronics	Mass.		30, 50, 70	6.0– 8.0	1–5		
464	Consulting	N.J.	×	10, 20, 32–34, 42, 43, 54, 71–73, 92	8.0–12.0	5–	30–36	I.E. Degree
465	Consulting	Mass.	×	Senior Engineer	12.0–15.0	10–15	32–50	I.E. Degree or Equiv.
470	Mining & Smelt.	N.M.		11, 13, 26, 36, 42, 45	5.0–7.0		–45	I.E. Degree Preferred
472	Plastic and Wood Prod.	Va.		11	8.0– 8.5	1–2	–30	MTM Experience(Woodwkg.)
479	Brass Products	Conn.		10, 20, 36		1–5		Math. Experience
491	Airline	Ill., Colo., Calif.	15%	11, 13, 18, 51, 70	6.0–10.0	1–5	–40	I.E. Degree Pref.
493	Plumbing Supplies	Ohio		11, 13, 18	7.5– 9.0	7–	30–35	I.E. Degree
494	Electronics	Utah		10–18, 34, 36, 40–46, 91	7.5– 9.0	5–10	30–40	I.E. Degree
499	Electronic Equip.	N.Y.		10, 36	Open	3–		I.E. Degree or Equiv.
503	Electronics	D.C.		30	9.0–11.7	5–		I.E. Degree
514	Air Force	Ohio	25%	12, 17, 18	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
515	Air Force	Ohio	25%	40	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
516	Air Force	Ohio	25%	32, 37	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
517	Air Force	Ohio	25%	10, 13, 16	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
518	Air Force	Ohio	25%	Broad I.E.	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
519	Automotive Parts	Mich.		10, 11, 13, 19, 26, 36, 38, 42	6.0– 9.0	7–20	30–45	College Degree
524	Utilities	D.C.		10, 13, 17, 37	6.0– 7.0	2–3	28–	I.E. Degree
534	Glass	N.Y.		11, 42, 43, 44, 45, 46, 47	7.0–	5–	30–40	I.E. or M.E. Degree
538	Papermaking	Pa.		50, 51, 52, 53, 54,55	Open	2–5	25–35	M.S.I.E.
539	U. S. Army	Ill.	×	37, 52, 54	8.8– 9.5	3–		B.S. Degree
541	Communications Mfg.	N.Y.		13, 43, 81	7.0–10.0	3–10	30–40	I.E. Degree or Equiv.
542	Electronics	N.Y.		19, 42, 43	5.2– 8.5	0–3		B.S.—I.E., I.M., or M.E.
543	Air Force (Maint.)	Pa.		11, 13, 18, 44, 53, 91	7.5	4–	25–40	I.E. Degree
545	Consulting	Pa.	×	10, 20, 30, 40, 50, 70, 90	8.0–10.0	5–	28–40	M.E. or I.E.
552	Smelt. & Titanium	Canada			7.0– 8.5	5–10		
553	Sugar Refining	Md., La.		11, 36, 38, 43	6.2–9.0	0–5		I.E. Degree
556	Office Machy.	Mich.		30	9.6–	3–5		Exp. in Quality Control
564	Education	N.D.		30, 40, 50	7.5–	8–	40–50	M.S./Ph.D. or P.E.
566	Education	Mo.		10, 30, 40, 50	Open			College Degree
567	Lumbering Mfg.-Cut Parts	La.		10, 30, 32, 33, 40, 48, 94	4.5– 6.5		25–40	
569	Transportation			10, 30, 42, 43, 47	8.4– 9.6	7–	30–	I.E. Degree
570	Transportation			10, 30, 42, 43, 47	7.0– 8.4	4–	20–	I.E. Degree
571	Transportation			10, 30, 42, 43, 47	6.0–	None	20–	I.E. Degree
572	Mgmt. Consultant	U.S.A. & Europe	×	10, 11, 13–18, 21, 22, 91 or 92	Open	5–	30–40	MTM Experience
585	Garment Mfg.	N.J.		10	5.2– 5.7	0–2		I.E. Degree
586	Glass Containers	Ind.		10, 11, 13, 14, 16, 21, 31, 36	6.3– 7.5	2–5	22–35	I.E. Degree Pref.
587	Naval Avionics	Ind.		11, 30, 40, 70	6.2– 7.5	2–4		I.E. Degree
588	Printing	Ohio		10, 20, 30, 40, 42, 43	Open	2–7	–30	I.E. or M.E. Degree
593	Metal Working	Mich.		10, 11, 13, 20, 39, 42	10.0–	10–		Engineering Degree
594	Chemical Mfg.	Tex.		11, 30, 32, 34, 43	7.0– 9.5	2–6	27–40	B.S.I.E.
595	Plastics	Ill.		11, 42–46	7.2– 8.4	5–		B.S.M.E. or B.S.I.E.
596	Mining & Refining	Ariz.		11–13, 18, 26, 28, 35, 36, 38, 48	6.5– 9.0		–40	
601	Wood and Plastics	Va.		21	7.5– 8.0	2–3	25–35	B.S. Degree
603	Training	Mich.		30—in Metal Cutting	7.0–	3–5	25–	B.S., M.S., Ph.D. I.E., M.E.
604	Training	Mich.		30—in Plastics	7.0–	3–5	25–	Same as above
607	Elect. Controls	Mass.		30,32,39	10.0–12.0	5–10	–40	I.E. or M.E. Degree
609	Research & Devel.	Md.		30, 40, 42		8–		B.S.I.E.
610	Research & Devel.	Md.		30		5–		B.S.I.E.
611	Research & Devel.	Md.		30		3–		B.S.I.E.
615	Heat Trans. Equip. Mfg.	Wis.		11, 14, 15, 19, 32, 38	6.6–	3–	–35	B.S.I.E. Pref.
617	Steel Goods Mfg.	N.M.		11, 31, 35, 54, 70	6.0– 8.0	3–5		I.E. Degree
618	Metalworking	Ohio		10, 11, 19, 32	Open	8		B.S.I.E.
619	Metal Casting & Machy.	Minn.		10, 30, 40, 44, 92	9.0–12.0	8–		
620	Food Machy. Mfg.	Iowa		36, 42, 43	6.0– 8.0	5–		M.E. Deg. or 2–3 Yrs. Col.
621	Boats	Mich.		30, 40	6.0– 8.4			
622	Casing Testers	Texas		30, 71		3–5	–35	B.S.I.E.
623	Semiconductors	Mass.		11, 13, 16, 19, 42	8.0–11.0	3–5		
624	Navy	D.C.		44, 49, 54, 70	4.5– 7.5		Open	
626	Mining, Milling, Smelting	Utah		92, 13, 21	7.9–10.7	5–		Engineering Degree
627	Railroad	Md.		35, 38, 54, 70–73	6.5–10.0	3–	25–	College Graduate
628	Paper & Pulp Mfg.	Maine		11, 18, 22, 43, 91	8.0– 9.0	5–	–40	I.E. Degree
629	Electronics	N.Y.		50–55				I.E. or B. A. with Math.
630	Textile & Paper Prod.	Tenn.		10, 11, 13–15, 18, 19, 21, 22, 26, 36	6.0– 7.5	2–3		I.E. Degree or Equiv.

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
631	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47, 90	7.5	3	20–	B.S. in Engineering
632	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	7.5	3	20–	B.S. in Engineering
633	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	6.2	2	20–	B.S. in Engineering
634	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	4.9	0	20–	B.S. in Engineering
635	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	5.8	1	20–	B.S. in Engineering
636	Air Force (Maint.)	Pa.		10, 11, 13–16, 18, 30–34, 39–47	6.2	2	20–	B.S. in Engineering
639	Education	N.Y.		10, 30, 40, 50, 60	9.0–12.0	5–15		Ph.D. in I.E.
640	Athletic Equip.	Ohio		11, 13, 16, 19, 26, 32–34, 42, 44	8.4–	5–6	30–40	MTM required
641	Athletic Equip.	Ohio		11, 13 16, 32, 42	6.5–	3–4	25–45	MTM required
642	Rubber (Ind. Prod.)	Mass.		10, 11, 13–15, 20–22, 32, 36, 38, 43, 42	Open	3–7	25–40	College Graduate
643	Pharmaceutical	Ind.		10, 11, 13–15, 18, 19, 42, 43, 53	5.7– 6.5	0–3		I.E. or M.E.
645	Management Cons.	Minn.	45%	13, 31, 37, 43, 53, 55, 71, 72, 91	11.0–	5–	29–45	Engineering Degree
646	Steel Mfg. & Fabr.	Ala.		30	Open	5–	28–45	Exp. in Steel Fabr.
647	Printing	Eastern U.S.		30	Open		30–45	B.S. in I.E. or Equiv.
650	Chemical Proc.	W. Va.		15, 17, 48, 91	6.0– 7.2	0–2		B.S.I.E.
651	Propane Equip.	Ill.		10	5.4– 6.0	3–		Degree not required
653	Research Lab.	Md.		30, 40 (Principal Engineer)		3–		B.S.I.E.
654	Research Lab.	Md.		30, 43 (Methods Analyst)		3–		B.S.I.E. or I.M.
655	Film	N.C.		10, 20, 30, 42, 43, 49, 53, 70, 73, 81	Open	0–5	21–30	I.E. Degree
656	Forgings, Stampings, etc.	Northeast		(Division Manager)	15.0–18.0	8–10	35–	I.E. Degree
657	Shirt Mfg.	Colo.		71, 90, 95	8.0–	8–	30–45	Shirt Mfg. & Records Exp.
658	Food Proc.	Minn.	Ltd.	10, 20, 30, 40, 81	5.2– 6.0	0–2	Open	I.E. or I.M. Degree
659	Machine Tool	Ohio		18,32	9.0–	10–	35–	M.E. or I.E. Degree
660	Consulting	N.Y.	×	10, 21, 36, 38, 91, 92	12.0–20.0	8–	35–45	M.E. or I.E. Degree
662	Papermaking	Pa.		Broad Experience	6.5– 8.0	0–3	21–30	I.E. Degree Pref.
663	Automotive	Pa.		31, 36, 38, 45, 53, 54, 71	6.7– 9.7	3–7	24–40	B.S. or B.A. Pref.
664	Automotive	Pa.		11, 14, 15, 18, 19, 22, 36, 45, 91	7.5– 9.7	4–12	23 45	B.S.I.E. Pref.
665	Automotive	Pa.		11, 14, 15, 18, 19, 22, 34, 36, 45	6.0– 7.9	1–6	23–31	B.S. or B.A. Pref.
666	Automotive	Pa.		11, 14, 15, 18, 19, 34, 36	5.5– 7.0	2–15	23–40	Degree not necessary
667	Soft Goods	Midwest		Manager of Mfg. Engineering	18.0–25.0		35–45	I.E. Degree—MTM exp.
669	Mining & Refining	Ariz.		11–13, 18, 26, 28, 35, 36, 38, 48	6.5– 9.0		-40	
670	Garment Mfg.	N.J.		54, 71	Open	0–3		B.S.I.E.
672	Electronic	N.Y.		10, 30, 42, 43	-12.0	5–		M.S. or B.S. in I.E.
673	Electronic	N.Y.		11, 13, 36	-12.0	2–		Electronic Exp.
674	Chemical Processing	Va.		10, 11, 14, 26, 43	Open	3–5	Open	B.S.I.E.
675	Power Farm Machinery	Iowa		General	Open	2–5	30–45	I.E. Degree
676	Clay Products	Tex.	Ltd	12, 21, 36, 42, 43	5.8– 6.6	5–	28–35	I.E. Degree or Equiv.
677	Garment	Miss.		10, 11, 15, 18 (Chief I.E.)	10.0–15.0			Exp. in Garment Ind.
678	Garment	Miss.		10, 11, 15, 18	5.0– 8.0			Exp. in Garment Ind. Des.
679	Education	Conn.		Asst./Associate Professor				Doctor's Degree in I.E.
680	Pulp & Paper	Maine, Pa.		11, 31–37, 43, 49, 91	6.0–	Open		B.S.I.E.
681	Diversified Mfg.	Ill.	Ltd	10, 20, 91	7.5– 9.5	5–	30–50	I.E. Degree or Equiv.
682	Heavy Ind. Equip.	Wis.		10, 11, 13, 18, 21, 22, 90, 91	10.0–15.0	10–	35–	I.E. Degree
683	Plastics	Midwest		11, 19, 30–33, 35, 39, 40–44, 47, 48, 80	8.0–15.0	10+	30–45	I. E. Degree or Equiv.
686	Lamp Mfg.	N.J.		10, 11, 14, 15, 20–23, 90, 92, 95	9.0–12.0		35–	I.E. Degree
687	Wood Furniture	Mo.		10, 11, 13, 21, 22, 36, 39, 47	7.0– 9.0	5	30–40	I.E. or M.E. Degree
688	Metal	Ind.		10, 13, 15, 30, 36, 40	Open	8–10	30–35	B.S.in Ind. Engineering
689	Corrugated Containers	Midwest		10–16, 21, 26, 60	6.0– 8.0	2–5	25–35	I.E. or M.E. Degree
690	Optical	N.Y.		10, 13, 19, 20, 36, 38, 42	9.0–12.0		35–45	I.E., M.E., and E.E. Degree
691	Navy	Hawaii		10, 20, 30, 40, 60, 70	7.5+	4		I.E. or Equiv.
692	Lab. Equip.	N.Y.		60–65, 71, 72	8.0–10.0	10	Open	
693	Education	Ohio		31, 37, 50	Open		30–50	Master's Degree Pref.
694	Communication	N.J.		10, 21, 30, 42, 43, 92	Open	5–7		Graduate Engineer
695	Electronics	Calif.		30, 32, 38, 39, 44	7.2	3		
698	Hospital	D.C.		10, 30, 50, 70	Open	3–5	25–55	B.S. Pref.
699	Hospital	Mo.		Broad	10.0+	0–3		Ph.D. Preferred or M.S.
700	Navy	D.C.	25%	10–18, 50–52, 54, 71, 72	5.5– 7.7+	1–	21–50	College Degree
701	Pharmaceutical	N.Y.		37, 50, 52, 53	6.6– 7.8	1–3		I.E. Degree
702	Pharmaceutical	N.Y.		11, 13, 14, 15, 18, 36, 38	6.0– 7.0	0–3		I.E. Degree
703	Tobacco Mfg.	W.Va.		11, 18, 42, 43	Open	1–3	23–28	I.E. Degree, must have satisf. Milit. Serv. Requirement
704	Government Agency	N.Y.		10–19, 70–72	6.4– 7.5	3–		B.S.I.E.
705	Synthetic Fibers	N.C.		10, 11, 13–20, 32–36, 42, 43, 50, 53, 81	Open	0–5		I.E. Degree
706	Tire & Rubber	Ohio		10–20, 36, 38, 70	8.0	3–4	-30	I.E. Degree
707	Education & Research	R.I.		10–20, 30, 40, 60	6.4– 8.5			I.E. Degree
708	Mining, Milling, Smelt.	Nev.		10, 11, 13, 14, 21	6.5–10.5	2+	-45	I.E. Degree or Equiv.
709	Textile	N.C. S.C.		28 for S.C. 10, 11, 18, 21, 26 (For N.C.)	7.0–	3–	-25	I.E. Degree
710	Food Processing	Minn.		50, 51, 52, 53	8.0–10.0	2–	25–35	M.S. in I.E. or Applied Math.
711	Aircraft	E.Pa.		92	13.0–17.0			Capable of Setting up and Directing all I.E.
712	Motor Mfg.	Ark.		10–20, 30, 40	6.0– 7.0	0–		I.E. Degree
713	Printing	N.Y.		13, 36, 42	5.2– 6.5	0–3		I.E. Degree
714	Navigation	Calif.		10, 36, 37, 38, 42, 43, 50, 53, 91	8.0–14.0	3–12	24–40	B.S.I.E., M.S.I.E. or Equiv.
715	Education	Mich.	Min.		7.0+	3–5		B.S., M.S., Ph.D. I.E. or M.E. with desire to teach
716	Elec. Mfg.	N.J.		92	Open	10 min.	Open	B.S.I.E. or M.E.
717	Chemical	Mass.		19, 30–33	7.0– 9.0		Open	I.E. with Mechanical Aeronautical Eng. Background
718	Rubber	Md.		10, 11, 15, 19, 21, 26, 30	Open			I.E. Degree or Equiv.
719	Metalworking	Pa.		14, 18, 22, 38, 42, 43	6.5– 7.5	4–6	30–40	I.E. Degree Desirable
720	Textile	Ga.		10–15, 18, 21, 22, 23, 34	6.0– 7.0	0–3	30–	I.E. Degree
721	Paper	Va.		10–18, 30–36, 41–47, 52, 53, 70, 81	6.4–	0–3	-30	I.E. Degree
722	Forest Products	Ark.		11, 30, 48	Open	3–4		I.E. Degree and or Adv. Degree
723	Forest Products	Ark.		10, 11, 13	Open	3–4		I.E. Degree and or Adv. Degree
724	Foundry	East. Pa.		10, 11, 14, 15, 21, 22, 43, 91	5.5– 7.5	2–	25–40	Mtm exp. Potential Chief I.E. Degree Opt.
725	Association	N.Y.		Program Director Mfg.	10.0–12.0		30–35	Broad Experience
726	Bedding	Minn.		11, 18, 30, 32, 35, 36, 40, 92	15.0–19.0	5–10	35–45	I.E. Degree
727	Grain Milling	Iowa		10, 11	Open			Prefer Grain Milling Exp.
728	Textile	N.C. Va.		10, 11, 14, 22, 28, 91	6.0– 8.0	2–6	21–35	College Graduate
729	Education	Ohio		10, 19, 30, 32, 39, 44, 47	7.0+	3–5	Under	

* These 3 Pϕ have openings in New York City, Detroit, Mich., Syracuse, N. Y., Indianapolis, Ind., and Cleveland, Ohio

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement (Production)
12	Methods Improvement (Office)
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic.
16	Predeter. Elemental Time Stds.
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

Entered as
second-class matter

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Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

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